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Proliferation Prevention in the Commercial Fuel Cycle

W. G. Sutcliffe

April 9, 1999

Lawrence Livermore National Laboratory

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Proliferation Prevention in the Commercial Fuel Cycle*

a collection of papers presented in Washington, DC
at the annual meeting of the American Nuclear Society, November 17, 1998

Manuscript date: April 9, 1999

Edited by
William G. Sutcliffe

Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550

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ABSTRACTS

The Proliferation Threat of Spent Fuel

by David Albright and Lauren Barbour

The focus of this paper is on irradiated or "spent" fuel and its proliferation implications. Most of our comments will focus on commercial, or power reactor, spent fuel, although any such discussion inevitably touches upon the problems in minimizing the proliferation risk posed by research reactor fuel. In fact, the only known case where a country moved to divert safeguarded fuel and turn it into nuclear weapons was Iraq. This fuel was foreign-supplied highly enriched uranium (HEU) for research reactors under International Atomic Energy Agency (IAEA) safeguards.

Discussion of Potential Vulnerability to Theft and Diversion

Jere P. Nichols

Fissile materials for covert nuclear weapons activities potentially can be acquired by theft or diversion of materials or technologies from peaceful nuclear programs, including those for production of electric power and radioisotopes. Barriers to such theft and diversion include enforcement of national laws prohibiting transfer of nuclear weapon materials and information, physical protection, safeguards administered by independent agencies, diversion-resistant fuel cycle processes, diversion-resistant chemical and physical forms of vulnerable materials, international export controls, and knowledge obtained with intelligence sources and methods (e.g., human intelligence, tracking of nuclear supplier networks, and surveillance by satellite photography).

This paper emphasizes technical considerations associated with some of the less conventional methods of covert diversion including: (1) upgrading of the enrichment of low-enriched uranium reactor fuel, (2) recovery of plutonium from aged spent fuel, (3) recovery of highly enriched uranium or plutonium from wastes, (4) production of fissile material (plutonium or 233U) by irradiation of targets in a power reactor, and (5) production of weapon-grade plutonium in research reactor/hot cell facilities designed for radioisotope production. Also emphasized are technical aspects of barriers to these types of diversion including: (1) self-protection associated with emissions of penetrating radiation; (2) other obstacles that must be overcome in recovery operations; (3) waste forms with recovery-resistance and unattractively-low concentration of fissile material; and (4) application of enhanced safeguards, including analysis and interpretation of samples taken in the environs of worldwide nuclear facilities.

Handling, Storage and Transportation of Spent Fuel, Plutonium, Mox Fuel and Waste: An Industry View

Jean-Claude Guais

In accumulating an operational experience of reprocessing more than 13,000 tons (MTU) of spent fuel from light water reactors, and some 300,000 MOX fuel rods used in 30 commercial reactors, a number of lessons have been learned in the areas of quality assurance, operations, safety, and security and safeguards. At this time both Russia and the USA are planning large programs for a proper disposition of their weapons plutonium. The record demonstrates that plutonium can be properly and efficiently handled, fabricated into MOX fuel, and burned in commercial reactors.

A BNFL Perspective on Security and International Safeguards in Plutonium Recycling Facilities

Roger Howsley

This paper will address the important role that recycling of nuclear fuel has to play in the management of plutonium for peaceful uses. It will be argued that plutonium should be viewed as a vital global energy source rather than a waste that needs to be currently stored or buried.
Currently, the energy created by the fissioning of plutonium in uranic fuel accounts for around 5% of the world's electricity and, in the UK alone, the value of electricity generated by plutonium is approximately £20 billion per year.

Clearly plutonium must be managed in a safe and secure environment if the benefits of plutonium generated energy are to be properly realised. BNFL has over forty years experience in the management of plutonium which has enabled it to become a world leader in plutonium technology and the development of security and safeguards systems for plutonium facilities. Extensive safeguards/verification arrangements with both Euratom and the IAEA have been in place for civil plutonium held at Sellafield for many years and recently, as a result of the UK's Strategic Defence Review it has been announced that surplus military plutonium and all future reprocessing activities in the UK will be subject to international safeguards and be available for IAEA verification.

A Proliferation Preventive Measure: An International-Monitored and Regional Storage System

Jor-Shan Choi

The management of spent fuel (SF) and high-level radioactive wastes (HLW) has become one of the most intractable problems associated with nuclear power generation. There are an increasing number of utilities whose SF and HLW inventories will exceed their storage capacities before the geologic repository is available. These utilities will have to expand interim storage, or face premature shut-down of their reactors. Dry storage is an option, but the storage casks/vaults are usually stored above-ground and at reactor sites, visible from local communities and raising anxiety and objection from the local public. A country's inability to site storage and disposal facilities within its national borders, due to limited land area and/or dense population, could eventually result in large accumulation of SF and HLW and the possibility of toppling its nuclear power program.

For as long as the problem of SF and HLW management and final repository disposal remain unresolved, the viability of nuclear power generation as an economic energy option will remain questionable. Therefore, a framework is proposed for an International-Monitored and Regional Storage System (IMRSS) for the management of SF and HLW.

Shifting Spent Fuel Policy from Reprocessing Toward Interim Storage: Case Studies in Germany, Japan, and Korea

Mark Hibbs

When civilian nuclear energy programs got underway in Germany, South Korea, and Japan in the beginning of the last quarter of this century, it was assumed that spent fuel would be an easily-managed and recyclable resource. Instead, as the year 2000 approaches the option of reprocessing spent fuel has come under enormous pressure in all three countries, and political opposition is growing to plans to site national repository and waste facilities. Utility management, critics of the plutonium fuel cycle, as well as politicians facing sensitive decisionmaking on the disposition of spent fuel and separated plutonium, are now therefore considering long-term dry storage of their growing spent fuel inventories as an indefinite solution. But in all three countries, the dry storage option is beset with question marks.

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Proliferation Prevention in the Commercial Fuel Cycle

Introduction

William G. Sutcliffe, Lawrence Livermore National Laboratory

This website contains the papers presented on November 17, 1998 during the session, "Proliferation Prevention in the Commercial Fuel Cycle," at the American Nuclear Society meeting in Washington, DC. The abstracts are in a separate section; individual papers also contain the author's bio and e-mail address.

In the session planning phase, it was suggested that the following questions and other relevant issues be addressed:

* What are the difficulties and issues with defining and enforcing international standards for the physical protection of Pu and HEU (beyond the Convention on the Physical Protection of Nuclear Material, which primarily addresses transportation)?

* How do we (or can we) keep nuclear technology in general, and reprocessing and enrichment technologies in particular, from spreading to undesirable organizations (including governments), in light of Article IV of the NPT? Specifically, can we (should we) prevent the construction of light-water reactors in Iran; and should we support the construction of light-water reactors in North Korea?

* Are there more proliferation-resistant fuel cycles that would be appropriate in developing countries?

* Can the concept of "nonproliferation credentials" be defined in a useful way?

* Is there historical evidence to indicate that reprocessing (or enrichment of HEU) in the US, Japan, or the EURATOM countries has impacted the acquisition (or attempted acquisition) of nuclear weapons by other nations or groups?

* What is the impact of a fissile material cutoff treaty (FMCT) be on commercial nuclear fuel cycles?

* Does MOX spent fuel present a greater proliferation risk than LEU spent fuel?

Although the authors did not explicitly attempt to answer all these questions, they did enlighten us about a number of these and related issues.

In his paper titled ***The Proliferation Threat of Spent Fuel,*** David Albright described proliferation implications of the stocks of spent fuel and separated plutonium around the world. He also warned us about not overlooking research reactor fuel and potential risk of separating neptunium from nuclear waste streams.

Jere Nichols' presentation, ***Vulnerability and Barriers to Theft and Diversion,*** discussed the vulnerabilities and barriers to illicit acquisition of fissile materials for weapons. The barriers include physical protection, safeguards, and diversion-resistant forms, processes, export controls and intelligence. Jere made a compelling case for environmental sampling as a deterrent to covert production.

Jean-Claude Guais discussed the industrial experience in handling, storing, and transporting spent fuel, plutonium, and MOX in the panel discussion on ***A Proliferation Preventive Measure: An International-Monitored and Regional Storage System.*** He commented on the lessons learned in the areas of quality assurance, operations, safety, and security and safeguards, and noted that excess weapons plutonium could be properly and efficiently handled, fabricated into MOX fuel, and burned in commercial reactors.

Roger Howsley, in a paper titled ***A BNFL Perspective on Security and International Safeguards in Plutonium Recycling Facilities,*** argued for the commercial recycling of plutonium as an energy source. He noted BNFL's experience and development of security and safeguards systems for plutonium facilities. He argued for the use of plutonium in MOX at this time, rather than storing it or disposing of it in spent fuel or an immobilization medium.

Jor-Shan Choi discussed the need for, and possibility of, the storage of spent fuel in internationally monitored regional facilities in his paper titled ***A Proliferation Preventive Measure: An International-Monitored and Regional Storage System.*** He noted the difficulties in obtaining acceptance of either geologic repositories or indefinite storage at reactor sites, and related these to the future of nuclear power.

In his paper titled ***Shifting Spent Fuel Policy from Reprocessing Toward Interim Storage: Case Studies in Germany, Japan, and Korea,*** Mark Hibbs discussed the prospects for recycling in a number of countries including Germany, South Korea, and Japan, noting the political opposition. He also noted the opposition to siting geologic repositories and the resulting consideration of long-term dry storage as an indefinite solution.

Acknowledgments

I wish to thank Mal McKibben from Savannah River for suggesting this session and helping me organize it. I also want to thank the authors for their very incisive papers and illuminating discussions. Finally, thanks are due to my colleagues at LLNL, Lyssa Campbell for putting the manuscripts together, and Ed Jones for financial support.

The Proliferation Threat of Spent Fuel

by David Albright and Lauren Barbour

Institute for Science and International Security (ISIS)

Prepared for the Panel "Proliferation Prevention in the Civil Fuel Cycle"
American Nuclear Society Meeting, Washington, DC
November 17, 1998

The focus of this paper is on irradiated or "spent" fuel and its proliferation implications. Most of our comments will focus on commercial, or power reactor, spent fuel, although any such discussion inevitably touches upon the problems in minimizing the proliferation risk posed by research reactor fuel. In fact, the only known case where a country moved to divert safeguarded fuel and turn it into nuclear weapons was Iraq. This fuel was foreign-supplied highly enriched uranium (HEU) for research reactors under International Atomic Energy Agency (IAEA) safeguards.

The Risk

Because irradiated or "spent" fuel contains fissionable materials, there is a risk that a country will extract these materials for fabrication into nuclear explosives. The main materials of concern are plutonium and highly enriched uranium. However, neptunium 237 and, to a lesser extent, americium isotopes are raising worries. They too, if in separated form, can be used to make nuclear explosives. As a result, we also include some information on these materials.

The risk posed by spent fuel varies with several technical and political factors. Leaving the spent fuel unreprocessed is in general seen as less risky than separating the nuclear explosive materials from the spent fuel. Spent fuel in unstable regions or countries or in facilities with poor materials control, accounting, and physical protection is also seen at greater risk. In the years that come, the risk will also depend on a number of political factors, including the outcome of several regional conflicts, the achievement of partial or complete nuclear disarmament, the fate of nuclear power and civil reprocessing, and the development of effective means to enforce international laws.

Even with the most optimistic "nuclear future," however, nuclear explosive materials will remain inherently dangerous and require careful attention. Successfully placing all spent fuel in geological repositories would not eliminate its risk, particularly if these repositories are in regions of conflict. However, national and international security is probably bolstered more by the case involving geological disposal than if large quantities of separated plutonium, highly enriched uranium, or neptunium 237 are in routine use and commerce.

Commercial Spent Fuel and Plutonium

At the end of 1997, about 180,000 to 190,000 tonnes of fuel from power reactors are estimated to have been discharged worldwide.[1] This spent fuel has been discharged in 31 countries and most regions of the world. The spent fuel contained about 1,100 tonnes of plutonium. This spent fuel also contained about 35 tonnes of neptunium 237 and about 45 tonnes of americium, almost all americium 241.[2] (The remainder is americium 242m and americium 243.)

Figure 1 shows the regional distribution of the plutonium produced in power reactors. Figure 2 shows the amount of plutonium (in spent fuel) in several countries, including many in regions of tension or with inadequate physical protection.

Annually, about 10,000 tonnes of spent fuel are discharged. This spent fuel contains about 70-75 tonnes of plutonium at discharge. Neptunium 237 stocks in spent fuel are growing at a rate of about three to five tonnes per year. Americium is growing at a rate of more than four tonnes per year, resulting mostly from the decay of plutonium 241. These values are expected to remain relatively constant during the next decade.

Over 50,000 tonnes of spent fuel, or over one-quarter of the total amount discharged, have been reprocessed through 1997. Most of this spent fuel is from gas-graphite reactors that use natural uranium fuel. Based on recent declarations by nine IAEA member states and on estimates of the Indian reprocessing program, about 170 tonnes of plutonium were in separated forms, as of the end of 1996.[3] Such a large surplus inventory was never intended; this "overhang" reflects extensive delays in commercializing breeder reactors and the difficulty of storing spent fuel from gas-graphite reactors.

Currently, about 20-25 tonnes per year of plutonium are being separated in civil reprocessing plants. This amount corresponds to roughly 3,000 tonnes of spent fuel, or about one-third of the total annual discharge of spent fuel. However, the amount of spent fuel reprocessed annually could decline significantly over the next decade. In addition, commercial reprocessing plants are confined to a handful of countries, all with long experience in this

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[1] The values for spent fuel and plutonium are updates of those in David Albright, Frans Berkhout, and William Walker *Plutonium and Highly Enriched Uranium 1996* (Oxford University Press: Oxford, 1997).

[2] David Albright and Lauren Barbour, "Troubles Tomorrow? Separated Neptunium 237 and Americium," from David Albright and Kevin O'Neill, eds., *The Challenges of Fissile Material Control*, Washington DC: Institute for Science and International Security (ISIS), 1999.

[3] *The Challenges of Fissile Material Control*, op. cit. A fraction of the separated plutonium has been fabricated into fuel and irradiated in fast or thermal reactors. Because of delays in breeder programs and the diminished value of plutonium following multiple recycling in LWRs, most MOX fuel will end up being stored as spent fuel.

industry. There is little prospect in the near-term of additional countries establishing commercial reprocessing facilities.

In 1997, about nine tonnes of separated plutonium were fabricated into MOX fuel, which is far below the amount separated annually, partly explaining the large inventory of separated plutonium.[4] Despite a planned increase in MOX capacity, separated plutonium inventories are expected to remain large at least during the next 10-20 years.

The surplus of separated plutonium will increase further because about 100 tonnes of separated plutonium from British, Russian, and US nuclear weapons programs have been declared excess to military needs. This plutonium is scheduled to be fabricated into MOX fuel or mixed with high level waste, although the start of actual disposition remains uncertain. The amount of excess military plutonium is expected to grow after the START arms control process resumes.

Virtually no neptunium 237 or americium has been separated from commercial spent fuel. During reprocessing, almost all of the neptunium and americium enter nuclear waste streams. Depending on the reprocessing plant, a fraction of the neptunium may also enter the separated plutonium product. In addition, small quantities of americium 241 have been separated as part of efforts to "clean up" separated civil and military plutonium.

Several countries are researching the partitioning and transmutation of their nuclear waste, which could increase the amount of separated neptunium and americium. Interest in partitioning and transmutation is expected to continue.

With diminished enthusiasm for commercial reprocessing and delays in fast reactor programs, countries have increasingly realized that long-term storage of spent fuel is a necessity. Some countries will continue to separate plutonium and use it in LWRs, but most states will concentrate on methods for the long-term storage of their spent fuel, at least during the next several decades.

However, the development of geological repositories remains an intensely controversial subject among the public. Often less appreciated is the inability of many smaller states to afford their own repository, especially as the costs of an adequate repository continue to escalate. As a result, many states have no choice but to defer their decisions about the ultimate fate of their spent fuel.

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[4] Noboru Oi, "Plutonium Challenges: Changing Dimensions of Global Cooperation," *IAEA Bulletin*, Vol. 40, No. 1, March 1998.

Research Reactor Fuel

Governments have acted to reduce the risk posed by both fresh and spent research reactor fuel. The reasons include the fact that the spent fuel is in general easier to reprocess, it contains highly enriched uranium, or it is at facilities that are inadequately protected.

More than 550 nuclear research reactors in over 50 states are operating or are shutdown in the world. About 20 tonnes of civil HEU is estimated to be at research reactors and fuel fabrication sites.[5] A number of these reactors have a surprising amount of spent fuel awaiting shipment for disposal. Many also have relatively large inventories of fresh HEU fuel.

Out of concern about the amount of fresh HEU in international commerce, the United States in cooperation with many other nations created the Reduced Enrichment for Research and Test Reactor (RERTR) program in the late 1970s. Its goal is to replace reactor fuels enriched to about 90 percent uranium 235 with fuels with 20 percent enriched uranium fuels. This level of enrichment is ideal from a proliferation perspective because the 20 percent material is extremely difficult to turn into a nuclear explosive, and very small quantities of plutonium are produced in the fuel during irradiation.

For several decades, the United States, which was the major exporter of HEU, had a policy to take-back U.S.-origin spent research reactor fuel. This policy was halted in 1988, pending the outcome of an environmental impact assessment.

This policy had been used effectively in reducing Taiwan's capability to make nuclear weapons. In the mid-1980s, the United States obtained Taiwan's permission to bring to the Savannah River Site in South Carolina the spent fuel from the Taiwan Research Reactor, which was long suspected of being linked to a nuclear weapons effort. However, a 1991 environmental ruling prevented the last shipment from being shipped to the United States.

During the 1990s, after an extensive domestic and international process, the U.S. successfully re-established its program to "take back" research reactor spent fuel of U.S.-origin. In total, the United States expects up to 104 operating and closed research reactors in 41 countries to send back a total of 3,000 kilograms of HEU containing about 2,000 kilograms of uranium 235 and more than 12,000 kilograms of low enriched uranium (average enrichment about 10 percent). The United States will pay the full cost for transporting and managing the spent fuel from developing countries.

Russia and Britain have also on a case-by-case basis accepted foreign spent fuel. Following the Persian Gulf War, Russia took Iraq's spent research reactor fuel, after public opposition prevented France and Britain from doing so. Recently, Britain accepted a small amount of fresh and spent HEU fuel from Georgia.

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[5] *Plutonium and Highly Enriched Uranium 1996*, op. cit.

Despite these successes, it remains very difficult to remove spent fuel from a site that is determined to be at risk. The United States is unable to take non-U.S.-origin spent fuel. Russia does not have a take-back policy for spent fuel it supplied.

Nonproliferation Implications and Policies

The proliferation implications of commercial reprocessing have been extensively debated. The interested reader is referred to *Plutonium and Highly Enriched Uranium 1996* for an elaboration of our position. Here, we would like to focus on the proliferation implications of keeping the plutonium (and other nuclear explosive materials) in spent fuel.

We believe that a "once-through" fuel cycle is in general more proliferation resistant than a "closed" fuel cycle. However, it is still possible that a nation will misuse commercial spent fuel, e.g. by building a clandestine, small-scale reprocessing plant.

An important historical lesson is that proliferant states have exploited all means to achieve their goals. Iraq sought a civil, safeguarded fuel cycle in the 1970s from several countries so that it could later clandestinely obtain plutonium for nuclear weapons via the irradiation of natural uranium targets in a large research reactor. Both Iraq and Pakistan depended on weak export controls to import gas centrifuge-related items.

Spent fuel from research reactors has proven attractive to proliferant states. Although no nonweapon state is known to have diverted power reactor spent fuel to weapons purposes, a state may find such fuel attractive in the absence of any other options.

Although some argued that a necessary defense against such misuse is a global ban on commercial reprocessing, such a ban has not occurred. Instead, the first line of defense against such potential misuse has been the creation of a two-tiered reprocessing world. In certain regions of the world, reprocessing activities are actively discouraged. Western nations also no longer consider selling commercial reprocessing plants to countries in regions of conflict or tension.

Consistent with this policy, the US-DPRK Agreed Framework of 1994 included a provision freezing operations at North Korea's gas-graphite spent fuel reprocessing plant. The 1995 LWR supply contract also contains a commitment by the DPRK not to reprocess or increase the enrichment level of any LWR fuel.

In recognition that small clandestine reprocessing plants can be built relatively quickly, some initiatives include the possibility of removing power reactor spent fuel from countries of concern. In the LWR supply contract, North Korea has given KEDO the right to take ownership of LWR spent fuel and to transfer it out of the country. Under the Agreed Framework, North Korea agreed implicitly to allow the spent fuel from its 5 megawatt-electric gas-graphite reactor to be removed to another country.

As part of its supply of a LWR to Iran, Russian officials have stated that they would take this reactor's spent fuel back unconditionally. However, this take-back policy appears to contradict a Russian environmental law, and the situation remains unclear.

Many stocks of fresh and spent HEU research reactor fuel remain in regions of tensions. Because many of the most vulnerable sites have fuel that was supplied by the former Soviet Union, a Russian take-back policy would be extremely valuable. Funding for such an effort would probably have to come from the West.

Although it is recognized that spent fuel poses proliferation problems and some provisions for the removal of spent fuel exist, no nation has a policy to accept research or power reactor spent fuel based solely on the security risk posed by such fuel. Even the US policy to take back U.S.-origin fuel does not allow it to remove the last shipment of spent fuel from the Taiwan Research Reactor or spent fuel from inadequately protected research facilities in the former Soviet Union. Discussions about accepting another country's spent fuel are so controversial that one has to ask: Will any nation be willing to take North Korea's spent fuel? Will Russia take Iran's spent fuel?

Complicating the development of take-back policies is the intense debate that surrounds nuclear waste in general and the development of a geological repository in particular. Few nations are willing to increase this controversy by stating a willingness to accept another country's spent fuel, regardless of the security need for removing spent fuel from a site.

If waste disposal and proliferation concerns can be satisfactorily addressed, developing methods to eliminate nuclear explosive materials may be an attractive goal. From both a proliferation and ethical perspective, it is undesirable to leave for future generations vast inventories of plutonium, neptunium, and other nuclear explosive materials, regardless of the disposition option. Because a way may be found to eliminate nuclear explosive materials once and for all, nations may want to delay disposing in an irretrievable manner their spent fuel in a geological repository.

But for the next several decades, the priority must remain on reducing the near-term proliferation risks posed by nuclear explosive materials. Toward this goal, the achievement of consensus on the means to dispose safely of nuclear waste must remain an urgent task.

About the Authors

David Albright, a physicist, is President of the Institute for Science and International Security (ISIS) in Washington, D.C. He directs the project work of ISIS, heads its fundraising efforts, and chairs its board of directors. In addition, he regularly publishes and conducts scientific research. He has written numerous assessments on secret nuclear weapons programs throughout the world. Albright has published assessments in Science, Scientific American, the Bulletin of the Atomic Scientists, Arms Control Today, The Washington Post, Newsday, The New York Times, The Public Interest Report, and Forum for Applied Research and Public Policy. Research reports by Albright have been published by the Environmental Policy Institute in Washington, D.C. and Princeton University's Center for Energy and Environmental Studies. Albright, in collaboration with Frans Berkhout, of Sussex University, and William Walker, of the University of St. Andrews, published World Inventory of Plutonium and Highly Enriched Uranium, 1992 (SIPRI and Oxford University Press). A second, greatly-expanded edition entitled Plutonium and Highly Enriched Uranium 1996: World Inventories, Capabilities and Policies was published in March 1997.

David Albright's e-mail address: isis@isis-online.org

Lauren Barbour is a Staff Scientist at the Institute for Science and International Security where she began as a Herbert J. Scoville Peace Fellow. A chemist by training, she has helped to prepare risk comparisons for the Colorado Department of Public Health and contributed to an IAEA assessment of wide-area environmental monitoring. She is preparing a report on the world inventories of civil plutonium and as well as tracking Iranian nuclear and missile developments.

Lauren recently co-authored a report on neptunium and americium for the ISIS publication, The Challenges of Fissile Material Control. She also co-authored an article for the Journal of the American Chemical Society.

Lauren graduated magna cum laude from Mount Holyoke College where she was elected to Phi Beta Kappa. Previously, she was an Associated Western Universities Summer Fellow at the Idaho National Environmental Engineering Laboratory.

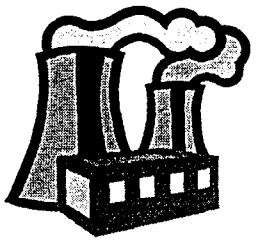
Lauren Barbour 's e-mail address: lbarbour@isis-online.org

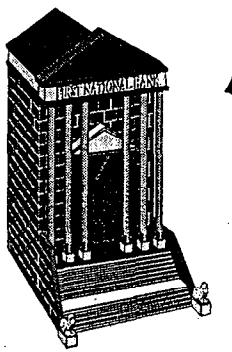
Vulnerability and Barriers to Theft and Diversion

Jere P. Nichols
Oak Ridge National Laboratory

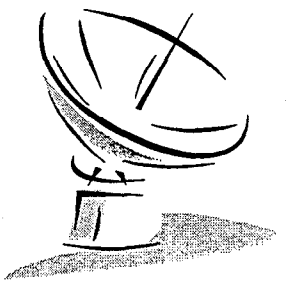
American Nuclear Society
Proliferation Prevention in the Commercial Fuel Cycle
Washington, D. C.
November 17, 1998

Proliferation prevention in nuclear power and radioisotope programs





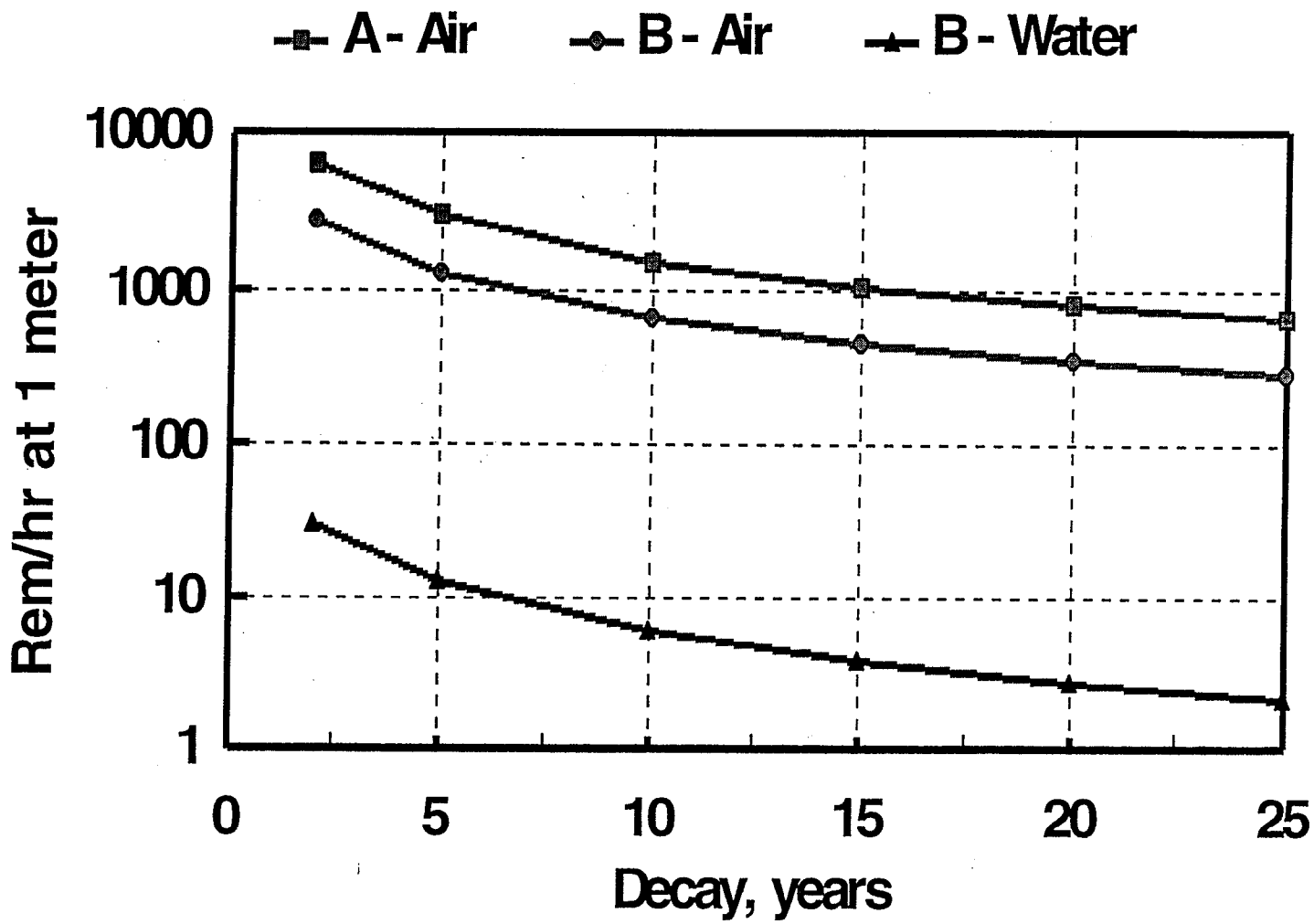
- Some vulnerabilities
  - Theft or diversion of weapons materials
  - Covert production of weapons materials



- Some barriers
  - National laws, international treaties
  - Physical protection
  - Safeguards by international organizations
  - Diversion-resistant processes and material forms
  - International export controls
  - Information (human, money flow, satellite photography)

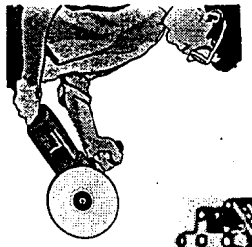
Emphasis

- Some vulnerabilities
  - Recovering Pu from spent fuel
  - Recovering HEU and Pu from wastes
  - Producing HEU from LEU
  - Producing Pu in research reactors and hot cells
- Some barriers
  - Self-protection by emissions of radiation
  - Diversion-resistant chemical and physical forms
  - Enhanced safeguards / environmental sampling



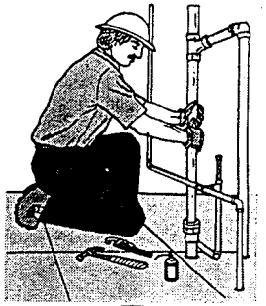
PWR 33 GWd/t dose rate at 1 meter vs decay

A B

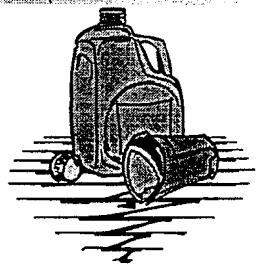


Recovering Plutonium from Spent Fuel

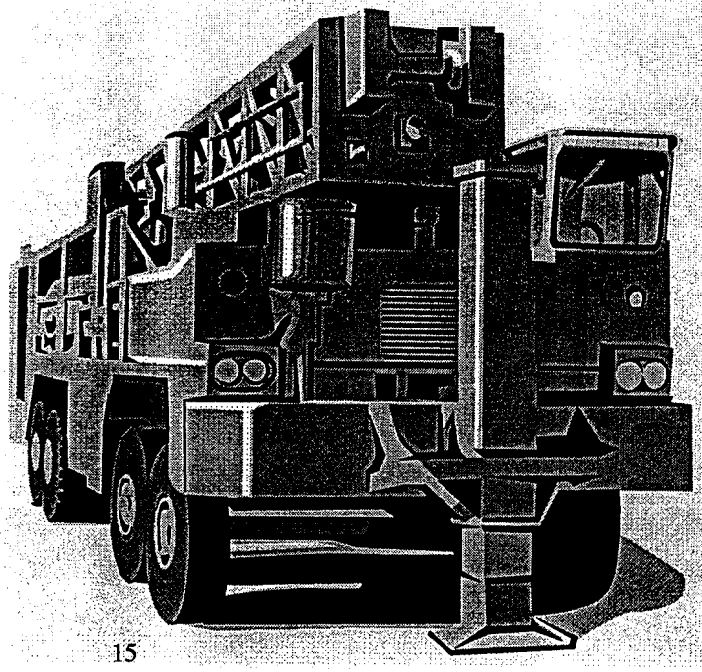
- Expose UO_2 by cutting or chopping

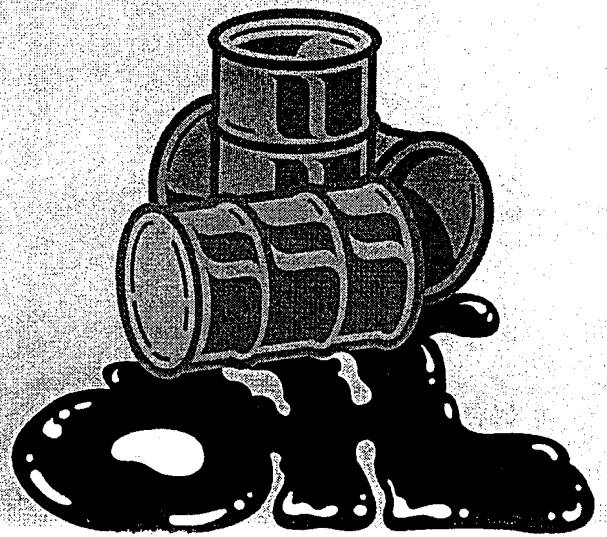


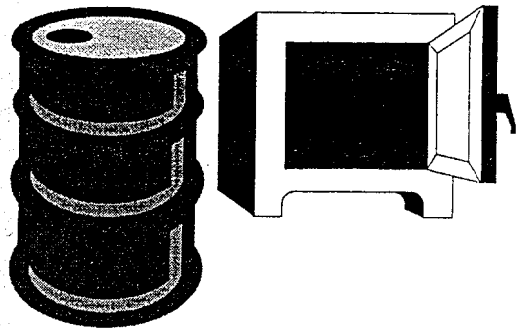
- Dissolve UO_2 in hot nitric acid
- Mix with TBP/kerosene to extract U and Pu
- Mix with aqueous reductant to recover Pu
- Purify Pu nitrate solution by ion exchange
- Add HF to precipitate PuF_3



- Dry and heat with Ca-I to make metal billet







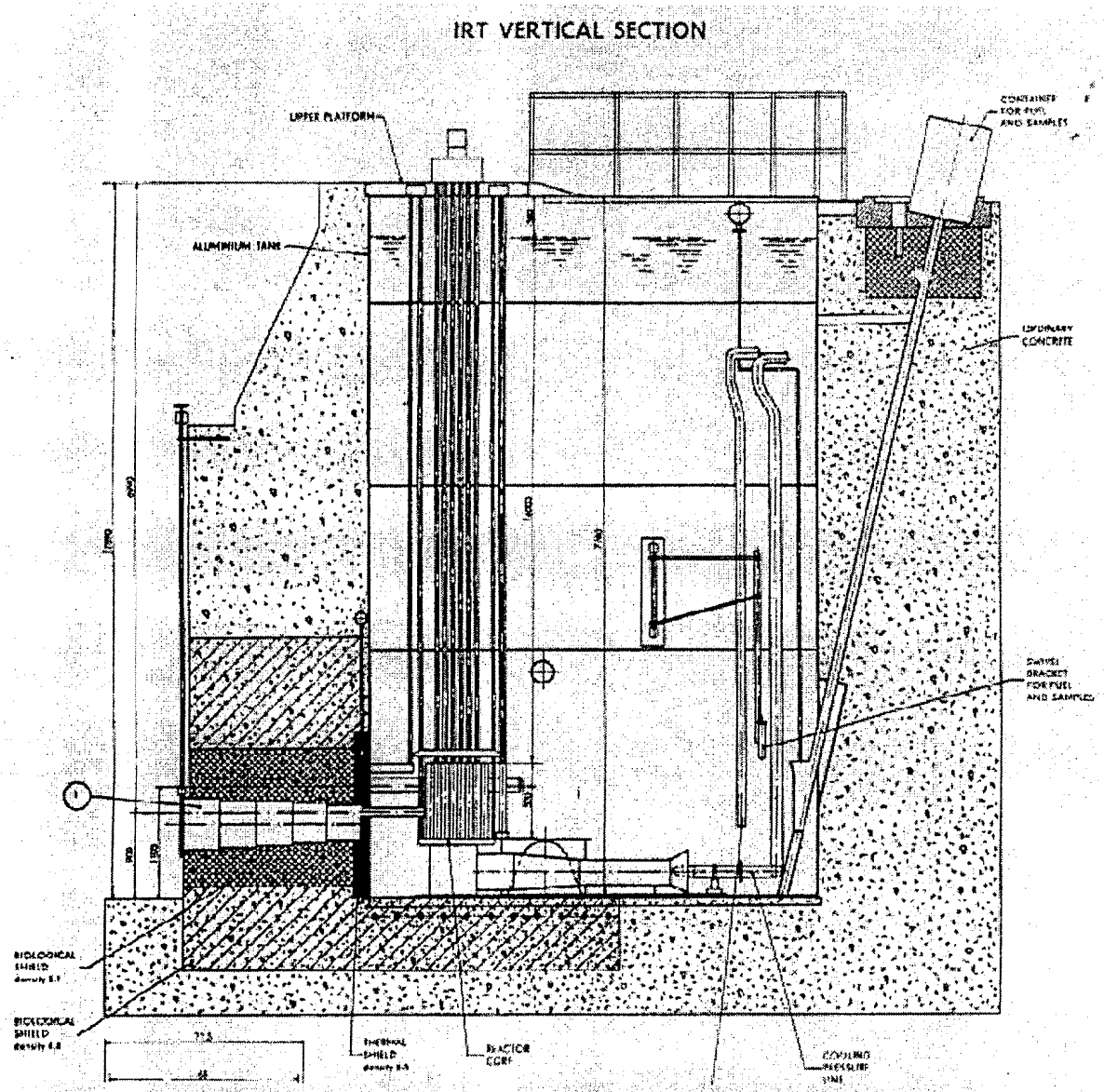
Assertions about waste forms for deterring recovery of U and Pu

- No realistic physical-chemical forms are effectively inert. "Inert" forms cannot reliably deter dissolution and recovery (e.g., Sulfex, Zirflex, Darex, Truex, GMODS).

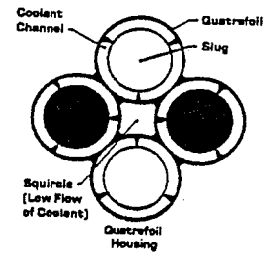
- Isotopic separations are difficult and expensive. Dilution with depleted uranium can protect ^{235}U and ^{233}U wastes.

- Processing large volumes and masses can be impractical. Low-loss processes leaving wastes with low concentrations of U and Pu can deter recovery.

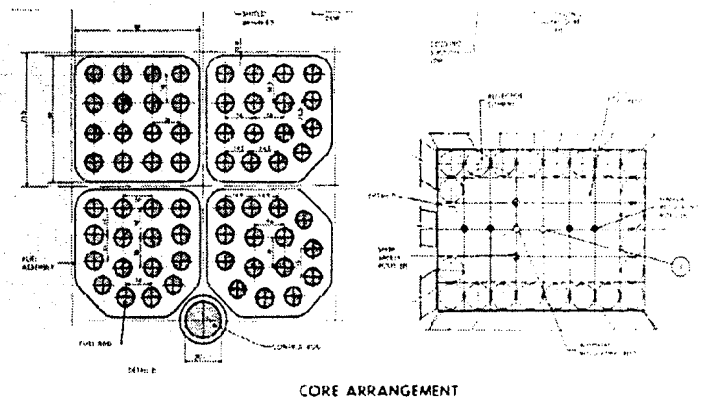
IRT Target Irradiation



Vertical section



Quatrefoil target

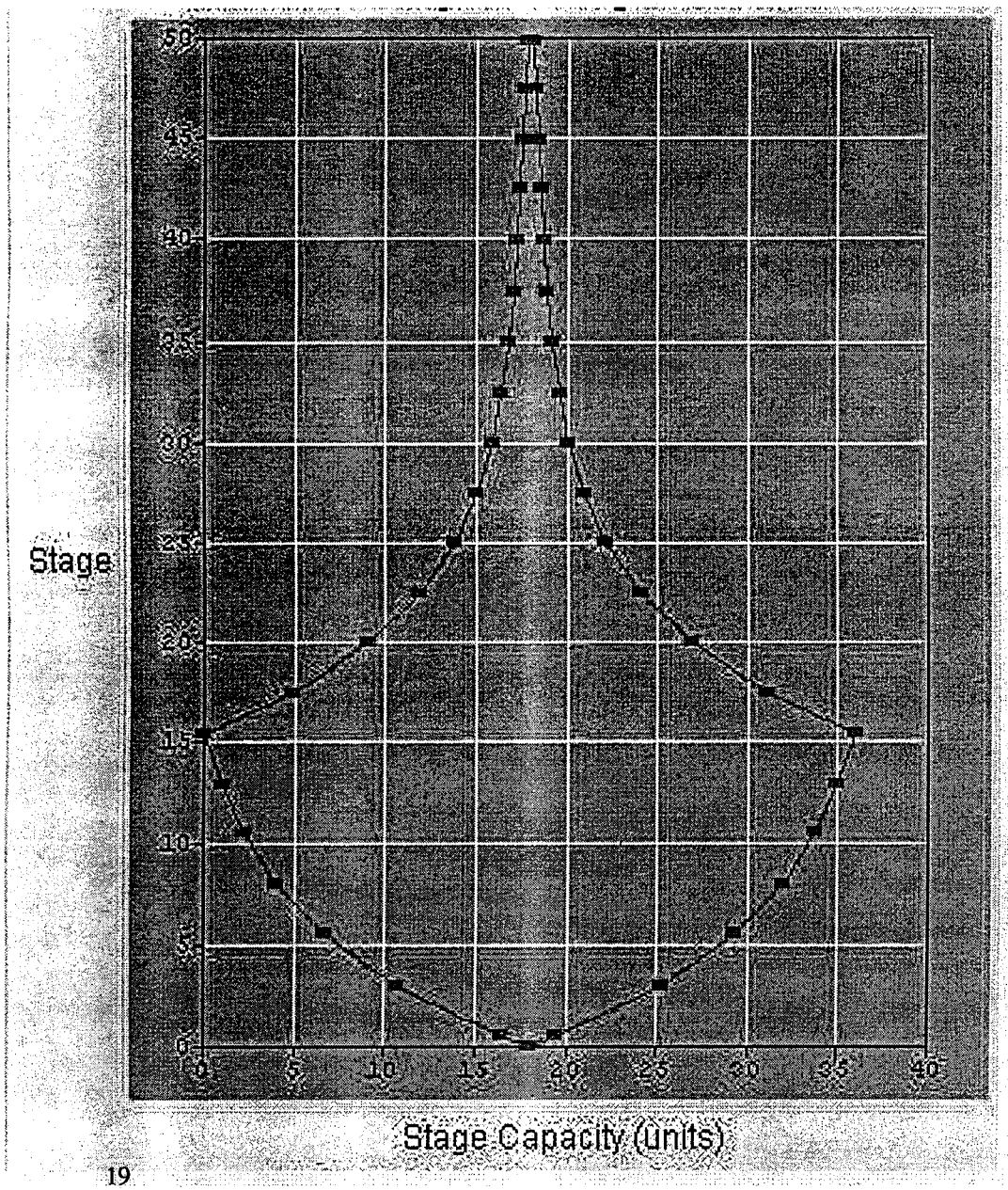


Core

	Irradiation time, days					
	0	50	100	150	200	250
Drivers						
Power, MWt	7.4	7.3	7.1	7.0	6.7	6.5
Burnup, MWd/t	0	66000	140000	220000	310000	430000
U, g	6000	5600	5200	4900	4500	4200
U-235, %	80	78	75	72	68	64
U-238, %	20	21	22	24	26	28
Pu, g		5	10	14	17	20
Pu-239, %		96	91	86	80	75
Pu-240, %		4	7	10	13	15
Targets						
Power, MWt	1.6	1.7	1.8	2.0	2.1	2.4
Burnup, MWd/t	0	165	340	530	740	980
U, g	584500	584300	584100	583900	583700	583500
U-235, %	1	1	1	1	1	1
U-238, %	99	99	99	99	99	99
Pu, g		105	211	319	430	545
Pu-239, %		99	98	97	96	95
Pu-240, %		1	2	3	4	5

IRT irradiation cycle with 30 driver elements and 6 quatrefoil targets

A centrifuge cascade for making 75 kg/yr of 90% ^{235}U from LEU

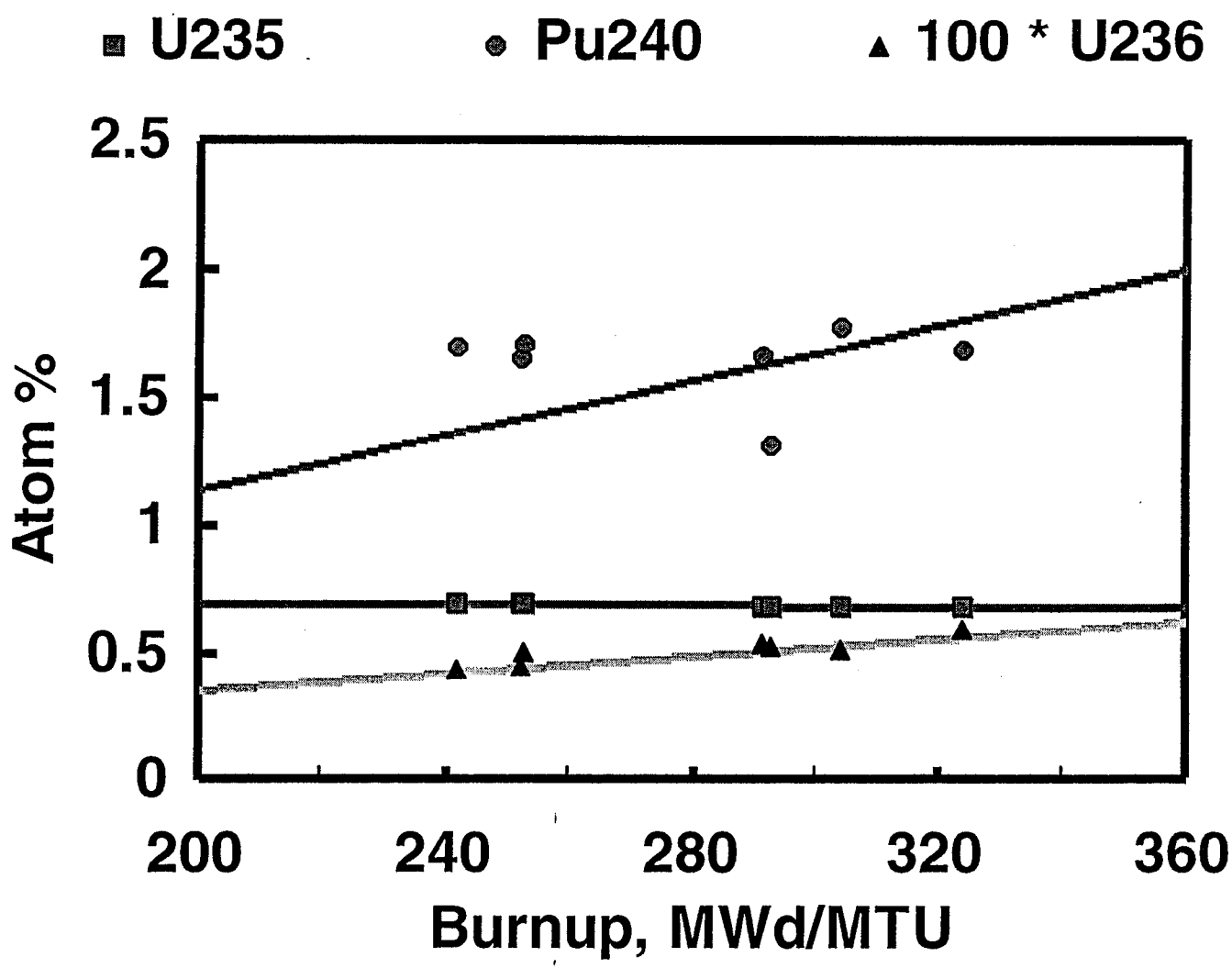


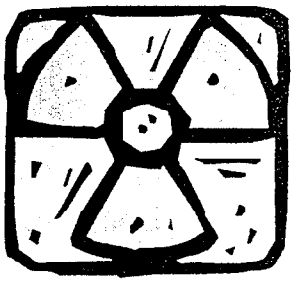
Feed: 2450 kg/y 3.0% ^{235}U
Tails: 2375 kg/y 0.3% ^{235}U
Capacity: 6200 SWU/yr
Bldg footprint: 450 m^2
Electricity: 50 kW
620 units, 50 stages
Unit sepn factor: 1.38
Unit capacity: 10 SWU/yr

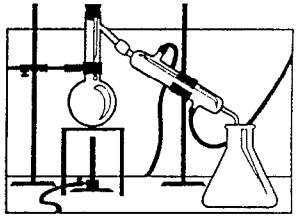
Enhanced Safeguards-Environmental Sampling

- Small airborne particles (e.g., swipes)
  - Retain isotopic composition of U and Pu
  - U/Pu isotopics accurately measured with TIMS
  - U with $^{235}U > 0.72\%$ is indicator of enrichment
  - U/Pu isotopics is indicator of reactor type, fuel burnup, decay time, and chemical separations

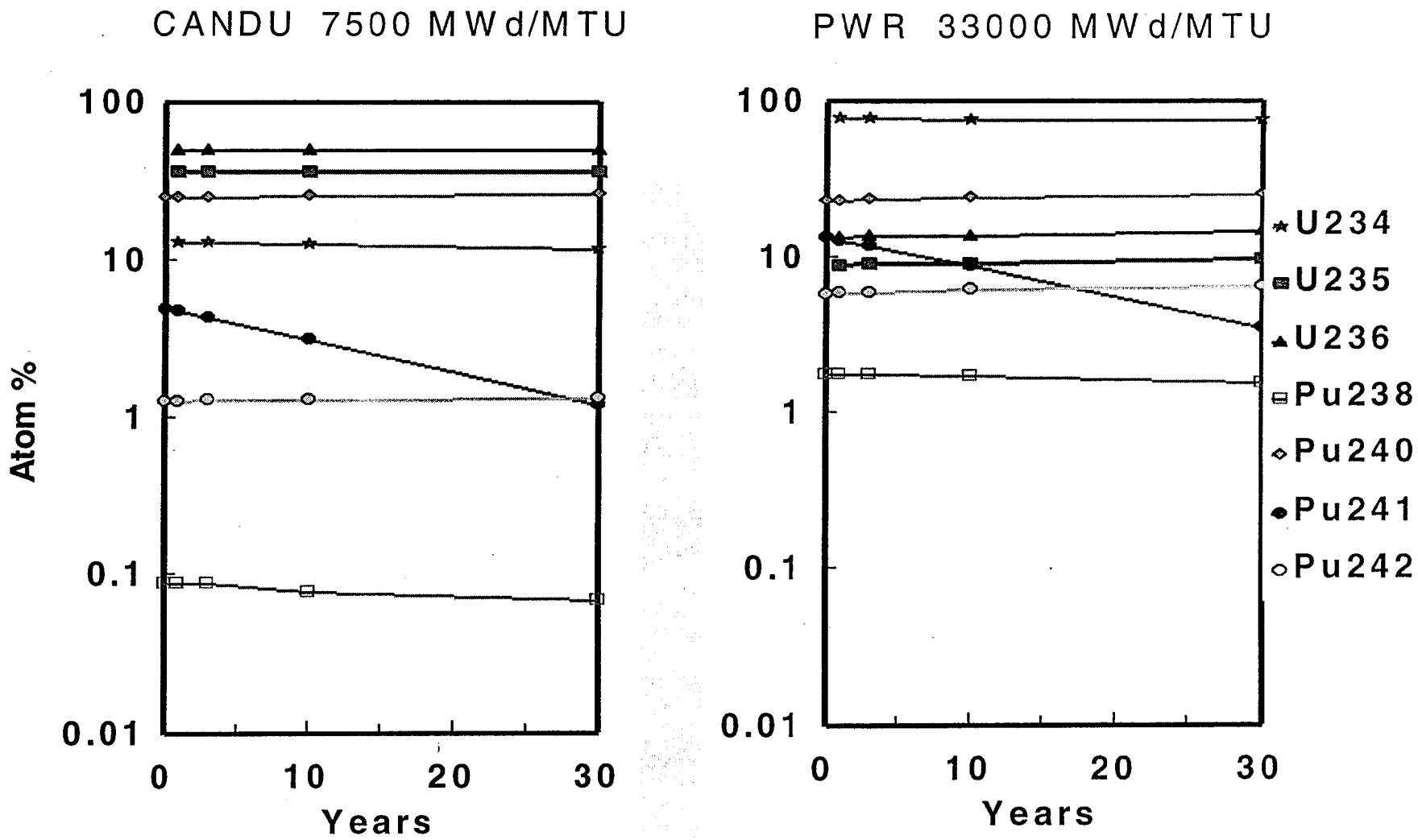
- Small bulk samples (e.g., swipes, leaves)
  - Retain ratios of fission and activation products
  - Many ratios accurately measured with HRGS
  - Ratios are indicators of reactor type, burnup, fuel decay, and irradiation of targets



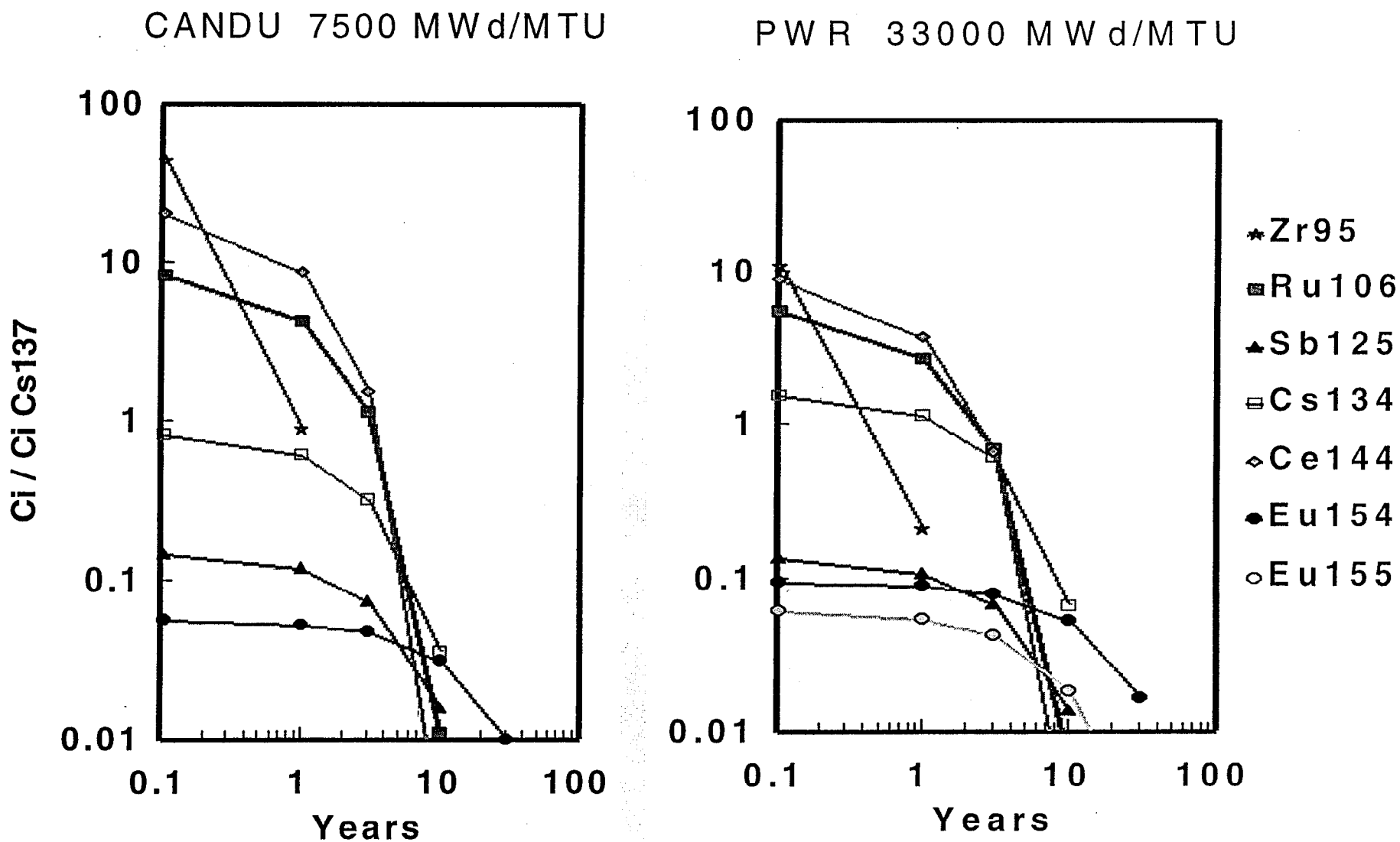




Analysis of seven particles indicated low burnup of natural U in a heavy water reactor



Samples can reveal separated Pu, time since separation, and method of production



Fission product ratios can indicate reactor type, burnup, and decay

In conclusion

- Spent fuel radiation deterrent can be circumvented with credible shields.
- Isotopic dilution or low concentration can protect wastes, not "inert" forms.
- There are credible scenarios for covert production of weapons-usable uranium and plutonium.
- Enhanced safeguards with environmental sampling can be an effective deterrent to covert production.

About the Author

Jere P. Nichols has over forty years experience, primarily at the Oak Ridge National Laboratory (ORNL), in design and analysis of (1) nuclear reactors (research, military, space); (2) radiochemical and nuclear fuel cycle plants; (3) nuclear waste management facilities; and (4) shipment of nuclear materials. His expertise includes Nuclear Criticality Safety, Nuclear Radiation Shielding, Nuclear Safety Analysis, and Nuclear Proliferation Analysis. His experience includes development responsibilities in uranium feed materials and spent fuel reprocessing; and design, analysis, or management responsibilities for ORNL reprocessing pilot plant, power reactor fuel reprocessing plant, transuranium element processing plant, thorium-uranium recycle facility, national radioactive waste repository, plutonium and U-233 purification and fuel fabrication facilities, Holifield Heavy Ion Accelerator, coal liquefaction/gasification pilot plant, fission-fusion hybrid reactor, High Flux Isotope Reactor, liquid-metal-cooled nuclear and chemical power sources for space power, gas-cooled reactors for military applications, and flywheel and other energy storage systems. Jere Nichols has contributed to books on radiation shielding, applications of radioisotopes, and high- temperature superconductors, and he is the author of numerous journal articles and technical reports.

Jere Nichols' e-mail address: nicholsjp@ornl.gov

ANS 1998 WINTER MEETING

PANEL: PROLIFERATION PREVENTION IN THE COMMERCIAL FUEL CYCLE

HANDLING, STORAGE AND TRANSPORTATION OF SPENT FUEL, PLUTONIUM, MOX FUEL AND WASTE: AN INDUSTRY VIEW

J.C. Guais, COGEMA, Inc.

ACTIVITIES INVOLVING SPENT FUEL, PLUTONIUM, MOX FUEL AND WASTE IN THE RCR (*) INDUSTRY

- SPENT FUEL UNLOADING AT THE REACTOR
- SPENT FUEL REPROCESSING AND WASTE CONDITIONING
- REPU (REPROCESSED URANIUM) REENRICHMENT
- MOX FUEL FABRICATION
- MOX FUEL USE IN REACTOR
- SPENT MOX FUEL MANAGEMENT

(*) RCR: REPROCESSING, CONDITIONING, RECYCLING

In fact each step includes a storage phase (cooling down, working inventory, ...) which can last from a few weeks to several years.

Between almost each step, transportation takes place from reactors to facilities, between facilities, back to a reactor (recycling material) or to a repository (waste).

THE VARIOUS STAKEHOLDERS OBJECTIVES AND AGENDAS

- THE UTILITIES: TO PRODUCE COMPETITIVE ELECTRICITY
  DAS: DEREGULATE AND SURVIVE
- THE INDUSTRY: TO PURSUE A SUSTAINABLE BUSINESS
  SIB: STAY IN BUSINESS
- THE GOVERNMENTS: TO OVERSEE THE VALUE OF THE NUCLEAR ENERGY PROGRAM
  PAP: POLICY AND POLITICS
- THE REGULATORY BODIES (INTERNATIONAL AND NATIONAL): TO SET AND APPLY SAFETY, SECURITY RULES
  ALARA: AS LOW AS REASONABLY ACHIEVABLE
- THE GENERAL PUBLIC: TO BE BETTER INFORMED/INVOLVED
  NIMBY: NOT IN MY BACK YARD
- THE OPPONENTS: TO OPPOSE
  NOMDB: NOT OVER MY DEAD BODY
- THE POLITICIANS: TO LEAD OR TO FOLLOW?
  NIMTOO: NOT IN MY TERM OF OFFICE
- THE MEDIA: TO MAKE THE NEWS
  GNINN: GOOD NEWS IS NO NEWS

THE VALUE OF RCR
(REPROCESSING/CONDITIONNING/RECYCLING)

- SAVING NATURAL RESOURCES: 20/30% OF NATURAL URANIUM THROUGH ONE SINGLE RECYCLING
- REDUCING WASTE VOLUME: FACTOR OF 4
- REDUCING WASTE TOXICITY: 0.1% OF PLUTONIUM IN ULTIMATE RESIDUES
- MAINTAINING ADVANCED NUCLEAR TECHNOLOGIES TO PREPARE NEXT GENERATION OF NUCLEAR ELECTRICITY SYSTEMS
- LONG-TERM ECONOMY
  MUST BE ASSESSED ON SPECIFIC COUNTRY/FACILITY BASES AND OVER THE LONG PERIOD. INCLUDES EXTERNALITIES
- NON-PROLIFERATION ADVANTAGES
  RECYCLING ACTUALLY BURNS HALF THE PLUTONIUM AND DETERIORATES THE REMAINING PART

SOURCES OF FISSILE MATERIAL FOR NUCLEAR WEAPONS

• NUCLEAR WEAPONS		(WEAPONS QUALITY)
• NUCLEAR WEAPONS COMPONENTS	- HEU - W-PU	
• SEPARATED FISSILE MATERIALS	- REPU - R-PU(*)	(COMMERCIAL QUALITY)
• FISSILE MATERIALS IN SPENT FUEL	- RESEARCH REACTORS - CANDUS(**) - LWRS(**)	
• FISSILE MATERIALS IN FRESH FUEL	- LEU IN UO2 FUEL(***) - R-PU IN MOX FUEL	
• NATURAL URANIUM(***)		

(*) Why do some people focus so intently on this "potential source", qualified by some experts as the worst quality material, and efficiently protected and safeguarded? (see added note on safeguarding)

(**) Spent fuel storage ATR (at the reactor) will multiply the sites and countries with potential sources of fissile material, more and more accessible as time passes.

(***) to be enriched as HEU with small clandestine enrichment cascades.

PROLIFERATION PATHS: DEVELOPMENT, ACQUISITION, DIVERSION, ... OF MATERIALS, TECHNOLOGIES AND KNOW-HOW

- FISSILE MATERIALS: HEU OR W-PU

  READY-MADE OR PRECURSORS (NATURAL URANIUM OR LOW ENRICHMENT URANIUM) + TECHNOLOGIES

- OTHER COMPONENTS

- DESIGN, ASSEMBLY, STORAGE

- DELIVERY SYSTEM

Note: Why do some people in the non proliferation community focus solely on the acquisition of fissile material, assuming somehow that the other steps, involving specific materials, processes, techniques, know-how, experience, ... are easily at hand or already mastered by the would be proliferator?

What about the delivery system?

THE INDUSTRY EXPERIENCE IN REPROCESSING

- 13,000 METRIC TONS LWR SPENT FUEL ALREADY REPROCESSED AT LA HAGUE

  99.88% OF PU RECOVERED (0.01% LEFT IN VITRIFIED RESIDUES)

- MOX SPENT FUEL REPROCESSING HAS BEEN DEMONSTRATED IN 1992 AT LA HAGUE (4.7 TONS)

- 8,000 GLASS CANISTERS (HLW) PRODUCED

  REDUCTION OF WASTE VOLUME (A FACTOR OF 4) AND RADIOTOXICITY

  (A FACTOR OF 20 TO 30%).

  NO PLUTONIUM MINE IN THE SPENT FUEL STORAGES, ACCESSIBLE AFTER A FEW DECADES (MOST FP DECAYED)

- TOTAL RADIOLOGICAL IMPACT OF REPROCESSING DISCHARGES:

  EACH YEAR MONITORING OF THE LA HAGUE ENVIRONMENT IS BASED ON 25,000 SAMPLES AT 820 LOCATIONS, REQUIRING 80,000 ANALYSES

  ANNUAL DISCHARGES ~ 0.02 mSv/year, TO BE COMPARED WITH ~2.4 mSv/year

  (120 TIMES HIGHER) = AVERAGE NATURAL RADIOACTIVITY IN FRANCE

THE INDUSTRY EXPERIENCE IN MOX FUEL RECYCLING

- MELOX PLANT NOMINAL CAPACITY (115 TONS OXIDE IN 1997) REACHED IN 2 YEARS OF START-UP OPERATIONS
- MELOX PLANT PRODUCES ONE 900 MWE PWR MOX ASSEMBLY PER DAY OR 100,000 PELLETS
- ANNUAL DOSE OF MOST WORKERS BELOW 5 mSv/YEAR, WHICH IS 10% OF THE CURRENT REGULATORY LIMIT
- MORE THAN 1000 MOX FUEL ASSEMBLIES LOADED IN EUROPEAN REACTORS

  BURN UPS UP TO 37,500 AND 45,000 MWD PER TON
- IN FRANCE, EDF WILL SOON SWITCH TO ITS MOX/UO2 PARITY PROGRAM (4-BATCH CORE MANAGEMENT)
- 31 REACTORS IN EUROPE WITH MOX FUEL

  THE OPERATORS REPORT NO DIFFERENCES WITH UO2 FUEL IN PERFORMANCES AND SAFETY

  16 REACTORS IN FRANCE

  10 REACTORS IN GERMANY

  3 REACTORS IN SWITZERLAND

  2 REACTORS IN BELGIUM
- JAPANESE PROGRAM PLANS MOX LOADING IN 16 TO 18 REACTORS BY 2010

THE INDUSTRY EXPERIENCE IN TRANSPORT

- 30 YEAR EXPERIENCE OF SHIPMENTS OF SPENT FUEL, PLUTONIUM, MOX FUEL AND WASTE IN FRANCE AND ABROAD

  FOR INSTANCE FOR FRESH MOX FUEL: 140 FS 69, THAT IS 280 MOX FUEL ASSEMBLIES, SENT FROM MELOX TO EDF REACTORS IN 1998

- MORE THAN 200 SPENT MOX FUEL ASSEMBLIES TRANSPORTED FROM EUROPEAN REACTORS TO LA HAGUE (MAINLY IN TN 12 CASKS: 12 SF ASSEMBLIES AMONG WHICH 4 ASSEMBLIES MAY BE MOX FUEL)

- OVER 160 SHIPMENTS OF SPENT FUEL (4,000 CASKS) COMPLETED SAFELY BETWEEN JAPAN AND EUROPE (PNTL SHIPS)

- 212 GLASS CANISTERS (9 CASKS) TRANSPORTED TO JAPAN (3 SHIPMENTS) AND GERMANY (2 SHIPMENTS)

About the Author

Jean-Claude Guais has 35 years of experience in nuclear energy, in both the scientific and the industrial fields. His vast experience encompassed both the domestic French program and the international scene. After completing his studies in Mathematics and Physics, he started with the French CEA in 1963 and was in charge of the theoretical and experimental studies in uranium enrichment. He then participated in the design, construction and start up of the Eurodif enrichment plant. He was also involved in other nuclear fuel cycle aspects. In 1983, he joined COGEMA where he was given several responsibilities in the Marketing Division, then the Reprocessing Division and several subsidiaries. He created and headed an in-house strategic Think Tank within the COGEMA Group. His present position is with COGEMA, Inc., Bethesda, MD, where he is Vice President for Strategic Development.

Jean-Claude Guais' e-mail address: jcguais@cogema-inc.com

A BNFL Perspective on Security and International Safeguards in Plutonium Recycling Facilities

Dr. Roger Howsley
Head of Security and International Safeguards, British Nuclear Fuels

Abstract

This paper will address the important role that recycling of nuclear fuel has to play in the management of plutonium for peaceful uses. It will be argued that plutonium should be viewed as a vital global energy source rather than a waste that needs to be stored or buried. Currently, the energy created by the fissioning of plutonium in uranic fuel accounts for around 5% of the world's electricity and, in the UK alone, the value of electricity generated by plutonium is approximately £20 billion per year.

Clearly plutonium must be managed in a safe and secure environment if the benefits of plutonium generated energy are to be properly realised. BNFL has over forty years experience in the management of plutonium which has enabled it to become a world leader in plutonium technology and the development of security and safeguards systems for plutonium facilities. Extensive safeguards/verification arrangements with both Euratom and the IAEA have been in place for civil plutonium held at Sellafield for many years.

The steadily increasing world population and the even more rapid increase in economic activity means that the world's demand for electricity could double or triple over the next fifty years. At the moment two thirds of this electricity is supplied by the burning of fossil fuels, with nuclear and hydro-power equally supplying the remainder. New renewables such as wind and wave power still supply only about 1% of electricity, and even the most optimistic projections for new renewables cannot meet the increasing demand in the time available. There is little hope for any expansion of hydro-power, so the bulk of the increased demand will have to be supplied either by the burning of even more fossils or by nuclear energy.

However, the world is increasingly recognising that the burning of fossils is not sustainable. The agreement last year at Kyoto was a first, but very small, step to reducing the emission of greenhouse gases and last week in Buenos Aires at COP 4 further progress was made to establish flexible trading mechanisms. I believe that as the evidence for global warming grows, even stronger measures will have to be taken and the electricity generation industry, responsible at present for one third of society's CO_2 emissions, will have to respond.

With sufficient political will, nuclear power could be significantly increased, but in its present form of thermal nuclear power reactors, the uranium reserves will last no longer than the reserves of fossil fuels. Various estimates put the lifetime of economic uranium reserves at less than 150 years, depending on the cost of extraction and demand. If we are to think long-term, as the nuclear industry must, then we need to continue to promote reactors that breed fuel. Ultimately, a 1 GWe Fast Breeder reactor can be fuelled by just 1.2 tonnes of depleted uranium

per year. At that level of requirement, the cost of uranium becomes almost irrelevant, so with billions of tonnes in sea-water alone, uranium becomes a truly sustainable energy resource.

But Fast Reactors also require a supply of plutonium. Indeed one of the early rationales behind reprocessing was to separate out the plutonium to fuel Fast Reactors. Our stocks of plutonium are now sufficient for this no longer to be a primary reason. But the main reason for reprocessing, as the best means of management of irradiated fuel, still remains.

Plutonium is generated as a by-product of uranium fission inside thermal reactors. But it is a very useful by-product as roughly one-third of the energy generated from the fuel already comes from the fissioning of that plutonium. So with nuclear power generating 17% of the world's electricity, around 5% could be deemed to be generated by plutonium. A simple calculation, valuing electricity at 2.5p per kilowatt-hour (about 4 cents/kw/hr) the UK pool price, puts the value of the electricity generated by plutonium at roughly £20 billion per year. So plutonium is already doing a valuable job, but it can do more.

There are essentially two things that can be done with the residual plutonium once the irradiated fuel is removed from the reactor. It can either be left in the fuel for ultimate disposal or it can be separated out.

In this paper I want to focus on the latter because in our view, separated plutonium, if properly managed presents no more of a proliferation risk than direct disposal of unreprocessed spent fuel.

There are four principal *options for the management of* separated plutonium that I wish to discuss. Firstly, storage, secondly immobilisation followed by disposal, thirdly incorporation into Fast Reactor fuel, and fourthly recycling as thermal MOX fuel. There are also some other technical options, such as transmutation, but these are not economically viable options today, and may never be. I will take these four options in turn.

The storage of plutonium is of course not a long-term solution, but it can be done entirely safely and securely provided that storage is done by a relatively limited number of experienced operators subject to stringent international safeguards. In the UK we have over 40 years experience of managing and protecting plutonium. We are subject to international safeguards under the auspices of Euratom, the European Safeguards Agency and the IAEA *and have an* overall national safety framework overseen by the Nuclear Installations Inspectorate. Our THORP and SMP facilities have some of the most advanced safeguards and physical protection features, including Near Real Time Materials Accountancy. We estimate that BNFL's investment in security since the mid 1980's has exceeded £250 million in today's money values. The highly trained, specialist police force who guard our sites and material movements have never once had to draw a firearm to protect any nuclear material in over 40 years.

Secondly to consider immobilisation. Of the various methods to achieve this, the most promising is probably incorporation into a glass matrix by vitrification. There is much international experience of the vitrification of High Level Waste. Vitrification and similar forms of encapsulation such as synroc have some advantages from a proliferation viewpoint over direct

disposal in that it makes the recovery and separation of the plutonium much harder but notably still not impossible. This option is being studied seriously, particularly in the US as a disposition route for *some* military plutonium, *such as residues unsuitable for recycling as fuel.*

The third option of incorporation into Fast Reactor fuel is no longer an imminent option except for the ongoing development programmes, but as I have already argued it is an option that must be kept open for the time when Fast Reactors will become economically attractive as an essential part of generating sustainable energy for the world.

The fourth option is to incorporate the plutonium into new fuel for thermal reactors. Mixed oxide (MOX) is now an established, proven technology which has been in existence for over 30 years since a reactor in Belgium was first loaded in 1963. In the same year MOX was loaded into the prototype Advanced Gas-Cooled Reactor, the WAGR, at Sellafield. Over 500 t of MOX fuel has now been manufactured world-wide, using about one third of the stock of separated plutonium. There are about 35 reactors licensed for the use of MOX. There could be 50-60 licensed reactors by the year 2000 (about 15% of all reactors world-wide) and there are no fundamental technical problems to the use of MOX in most PWRs. Certainly, the security and safeguards arrangements at MOX plants and reactors are clearly defined and routinely applied.

At BNFL in addition to the manufacture of all the plutonium based fuel for the UK's experimental Fast Reactors we have been operating a small scale MOX Demonstration Facility, MDF, for thermal reactor fuel for several years. Fuel from that facility has already been loaded into reactors in Germany and Switzerland. Our much larger Sellafield MOX Plant, SMP with a capacity of 120 tonnes of heavy metal per year is nearing completion, and has now entered a phase of public consultation prior to commissioning. The co-location of reprocessing and fuel plant at Sellafield, is a key element in reducing the need for transport of plutonium in a separated form.

But of course, there will be a continuing need for the transport of plutonium in some form. In BNFL we have many years experience of the safe national and international transport of nuclear materials. We have a long association with our French and Japanese partners through our subsidiary PNTL, which, in addition to the transport of irradiated fuel from Japan to France and Britain, has made return shipments of High Level Waste and of plutonium for the MONJU reactor. We have been safely transporting plutonium for over 30 years, and more recently a number of MOX assemblies have been transported to European utilities by air and sea. Of course, all transport is subject to strict international regulation by the IAEA. The outstanding safety record is due to the design and development of the packaging, the experience and expertise of the operators and the rigorous checks that are carried out at every stage of the operation.

With a 30% MOX fuel loading, a thermal reactor can consume as much plutonium as it produces. When SMP and JNFL's JMOX plant are on-line and with an extension to the French MELOX plant, some time after the year 2000, there will be sufficient capacity to stabilise and reduce civil plutonium stockpiles. The IAEA estimates that the stocks of separated plutonium will roughly halve over a period of 10 years once these plants are operational. As more advanced

reactors capable of higher MOX loading are developed and more reactors are licensed to use MOX, the entire production and consumption of plutonium will become increasingly stabilised.

There are five key advantages to MOX fuel which I want to outline:

Firstly and in contrast to uranium fuels, it can effectively stabilise or reduce the total plutonium inventory, both civil and military.

Secondly, plutonium is itself a valuable energy source. Just one kilogram of plutonium has the energy potential of one thousand tonnes of oil. Future generations may regard us as mad to throw away and make inaccessible such an energy source. And of increasing importance, it is a carbon-free energy source, each kilogram of plutonium recycled saving the discharge of more than three thousand tonnes of CO_2.

Thirdly, such plutonium will remain visible, or for ex-military plutonium become visible, as part of the civil safeguards regime, so that the potential or opportunity for clandestine diversion will be minimised. Significantly, it will be European plutonium technology, developed entirely for civil purposes that will be used in the US to convert surplus military plutonium into MOX fuels, under full IAEA safeguards.

Fourthly, recycling reduces both the amount of waste and the number of spent fuel elements that will require ultimate disposal.

And fifthly, we will maintain and develop the skills and capabilities that will be needed longer-term when as I believe the inevitable resurrection of nuclear power occurs and the need for efficient, commercial breeder power stations emerges.

The current economics of MOX fuel are often misunderstood. The fuel currently costs four to six times as much to fabricate as virgin uranium fuel, but it can save up to £50M over the lifetime of a reactor by offsetting the cost of mining, purifying and enriching new uranium. MOX will become more widely economic with improved manufacturing experience and as more advanced reactors with higher burn-ups are developed. For these reactors the alternative to MOX is more highly enriched, more expensive uranium fuel, making MOX ever more attractive.

Finally, I wish to address what are perceived as the three principal risks associated with the management of plutonium.

Firstly, there is the risk of a NPT state deliberately diverting nuclear materials or facilities from civil to military use. This is predominately a political issue, which requires effective international surveillance and safeguards. As the world becomes more connected and surveillance techniques increasingly improve, I believe that the chances of a rogue state being able, let alone wishing, to default on its Non-Proliferation commitments will become increasingly remote. To strengthen this point I believe firmly in developing international commercial and technical partnerships for the management and control of all the relevant nuclear activities. This is an important aid to the safeguards regulatory and inspection regimes.

Secondly, there is the risk of the theft of nuclear materials by terrorist or other groups. This risk has been enhanced by the ending of the cold war and the release from strict military supervision of significant quantities of nuclear materials. It should be noted that there is no evidence of any credible risk of diversion of civil safeguarded material. However, the theft of any nuclear material is a risk that needs to be addressed very seriously and it is. In this context I wish to clarify one important misconception about the security and safeguards regime which applies to special nuclear materials. Critics of plutonium recycle frequently argue that the risks associated with plutonium fuels are far higher than for uranium fuel because of the proliferation potential. In truth, the international security and safeguards regime has always had as its core philosophy a regulatory approach which minimises and equalises the potential risks from different nuclear materials. This means that the requirements and regulations for securing and safeguarding plutonium based fuels already take into account the possibility of theft or diversion, the time and technology needed by sub national groups, including terrorists, to try and fabricate an improvised nuclear device and in response, applies a wide range of effective counter measures to prevent this happening.

Thirdly, there is a risk that the nuclear power option could be closed off by political decision. This could perversely leave the world more open to the threat of nuclear proliferation. Nuclear materials exist and will continue to exist. They can best be controlled by ensuring that we maintain viable and peaceful outlets. We must continue to convince the public that the civil use of plutonium is actually a solution to plutonium proliferation and not part of the problem. We must also ensure that Governments receive a balanced view, and trust that they will be able to resist short-term single-issue populist lobbying and take seriously their moral obligations to heed the longer-term needs of world populations.

I have outlined a number of approaches to the management of plutonium. All of these will have to be pursued to some extent, but the most important of these for the immediate future is the thermal MOX option. Its pursuit is a key element of both the effective management of plutonium and of the long-term maintenance of nuclear power as an environmentally beneficial and sustainable energy resource.

About the Author

Dr. Roger Howsley is Head of Security and International Safeguards at BNFL. Dr Howsley holds a first class honours degree and Ph.D. in Life Sciences. In 1981 he joined BNFL rather than continue post doctoral research in the USA on the possible existence of life on Mars. (He has no regrets.) In 1982 he transferred to BNFL's International Safeguards team and gained first hand experience of nuclear materials accountancy issues and safeguards inspections. By 1991, he was appointed Head of BNFL's Security and International Safeguards Department and is responsible for those policy areas across the BNFL group of companies. He has extensive international experience in working with the IAEA and Euratom and with National Police Forces and security organisations. He also has a strong professional interest in the climate change debate and the contribution that can be made by nuclear power to mitigate increases in atmospheric carbon dioxide.

Roger Howsley's e-mail address: roger.howsley@bnfl.com

A Proliferation Preventive Measure: An International-Monitored and Regional Storage System*

Jor-Shan Choi**

Lawrence Livermore National Laboratory

Abstract

The management of spent fuel (SF) and high-level radioactive wastes (HLW) has become one of the most intractable problems associated with nuclear power generation. There are an increased number of utilities whose SF and HLW inventories would exceed their storage capacities before the geologic repository is available. Utilities with SF exceeding their original storage capacities would have to provide interim storage for SF, or face premature shut-down of their reactors. On-site dry storage is an option, but the storage casks/vaults are usually stored above-ground and at reactor sites, visible from local communities and raising anxiety and objection from the local public. At the end of plant life when revenue is no longer generated and decontamination and decommissioning of the plant site is considered, decisions on where to relocate the dry SF casks/vaults would have to be made.

Some countries' utilities send their spent fuel to off-site fuel-reprocessing. The intent here is to recover the plutonium and uranium from other highly radioactive materials in the spent fuel. And by so doing, the utility could avoid the need for interim storage of spent fuel. However, The separated plutonium from fuel reprocessing would have to be fabricated and recycled as MOX fuel in reactors, or be indefinitely in safe and secured stores. The reprocessed uranium would be stored until its recycle is economically viable. And the vitrified HLW, would have to be in safe store until a final geologic disposal site is available.

The separated plutonium, deemed "nuclear-weapons usable" could be a concern for nuclear proliferation, and theft and diversion, especially in countries where appropriate material controls and accountability systems are not well in place.

For as long as the problem of SF and HLW management and the final disposition of the separated plutonium (civil and weapons-grades) remain unresolved, the viability of nuclear power generation as an economic energy option would remain questionable. This paper proposes a framework for an International-Monitored and Regional Storage System (IMRSS) for the management of SF, HLW, and the separated plutonium inventories from both civil and weapons sources. The framework would be evaluated from the standpoint of nuclear non-proliferation, and radioactive wastes management.

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* This paper is based on an independent study for the Pacific Nuclear Council's Steering Committee on SF/HLW management by the author when he was employed by Lawrence Livermore National Laboratory (LLNL). The viewpoints expressed here are strictly those of the author; past and present affiliations may not agree.

** Current address: International Atomic Energy Agency (IAEA), Wagramerstrasse 5, P.O. Box 100, A-1400, Vienna, Austria

1. Introduction

1.1 Spent fuel arising and the need for interim and/or long-term storage

The current annual spent fuel discharged from all power reactors world-wide (for a nuclear capacity of 352 GWe) is about 10,500 tonnes of heavy metal (tHM). Table 1 shows the at-reactor storage capacity and inventory, the available interim storage capacity, the 5-year discharge inventory, and the need for additional storage in the next 5-years for each country operating power reactors and holding spent fuel stocks. The 5-year discharge inventory is used here to establish the need and to allow the utilities and countries enough lead time to provide for additional SF storage capacity.

Table 1 shows that countries have the most urgent need for additional SF storage capacity in the next 5 years are those in East Asia and Eastern Europe. Countries in other regions will eventually have such need though it may arise in some later time.

1.2 Separated plutonium inventories

The global reprocessing capacity is approximately 5000 tHM/y. If fully utilized, this could accommodate about half of the annual spent fuel discharged. Most of the separated civil plutonium from reprocessing is destined for MOX fabrication and recycled back to light-water reactors (LWRs). However, some separated plutonium is stored pending decisions on its final disposition.

It is reported in the Plutonium Management Guideline[1] where nine countries declare their current holdings of separated civil plutonium inventories that their total inventory is more than 160 tonnes in 1998 (as shown in Table 2). Although not all countries holding separated civil plutonium are in the Guideline, the declaration reveals more than 90% of the total global inventory. In addition, the US and Russia Federation has each declared an excess of 50 tonnes of weapons-grade plutonium from their dismantled nuclear-weapons.

1.3 Once-through MOX recycling

As of 1998, there are 38 nuclear power reactors licensed to use MOX. Of these, 34 LWRs are loaded partially (~1/3 core) with MOX fuel from the civil plutonium stocks and manufactured by mature fabrication processes. The accumulated experience in MOX fuel utilization (more than 1,000 MOX fuel assemblies had been loaded into the European reactors) demonstrates that the MOX can be used in power reactors and its performance is comparable to UO_2 fuel in normal and abnormal reactor conditions.

However, the discharged spent MOX fuel assemblies are not currently reprocessed. This is primarily because of the low economic incentive for recycling the plutonium from spent MOX fuel. This once-through MOX fuel cycle where the spent MOX fuel is indefinitely stored could reduce the risk for nuclear proliferation by reducing the separated civil plutonium inventories, although, its overall fuel-cycle economics may not be as favourable if reprocessing and successive recycling of plutonium could be realized for the conservation of the uranium resource.

The discharged MOX spent fuel will add to the global SF inventories, requiring interim and/or long-term storage. It may eventually be disposed of in geologic repository.

1.4 Reprocessed uranium and the vitrified HLW

Spent-fuel reprocessing produces reprocessed uranium (RU). The RU contains ~0.8% U^{235} and can be re-enriched to low-enriched uranium (LEU, which accounted for the neutron-poison effect of U^{236} in RU) and recycled back to the reactor. No large-scale recycling of RU is currently practised because of the low economic incentive caused by the low natural uranium price. Hence, the RU is converted to a stable chemical form (oxide) and stored at the reprocessing sites. Some RU may have returned to its original owners/utilities for storage.

The vitrified HLW canisters are returned to its original owners/utilities from the reprocessors. They would have to be stored at interim storage until a permanent geologic repository is available for their final disposal.

2. International-Monitored and Regional Storage System

The International Atomic Energy Agency (IAEA)'s Joint Convention[2] on the Safety of Spent Fuel and Radioactive Waste management recognizes that the ultimate responsibility for ensuring the safety of spent fuel and radioactive waste management rests with the country which produces them. There are also international (IAEA) and regional (Euratom) safeguards and security systems for material controls and accountability of the separated fissile materials (plutonium, U^{235}, and U^{233}).

The IMRSS concept defined here is based on the IAEA's Joint Convention that SF storage facilities, regardless whether they are operated at national or regional/international level, have to be treated in a similar fashion as far as the application of safety principles and standards are concerned; that is, similar criteria, evaluations and procedures apply at both the national and regional/international levels. The SF to be managed by the IMRSS includes both the spent UO_2 and MOX fuel. The RU could also be managed by the IMRSS.

The IMRSS concept is not a substitute of a country's national SF/HLW management system, but rather a bilateral or multilateral SF/HLW management system formed under contract between two or more parties, with its sole purpose of complementing a country's national system. The IMRSS, once formed, is applicable within a contractual period which begins when a participating country deposits its SF or HLW into a custodian country and ends when that participating country decides to withdraw the SF or HLW.

During the contractual period, the custodian country would be responsible for the safe and secure storage of SF and HLW, and the participating country would respect the sovereignty of the custodian country providing the IMRSS service, but retain the legal ownership of its SF and HLW. Also, the IMRSS service provider(s) would receive financial compensation from other contractual parties.

The IMRSS concept would consider:

* **Sovereignty** of the countries providing the IMRSS services, as regards to the use of their respective territories for the purpose of carrying out the IMRSS activities,

* **Legal Ownership** of the SF and HLW, and the contained fissile material,

* **Custodianship** of the SF and HLW, and the agreed terms which govern them during the contractual period set by the IMRSS,

* **Proximity** of the participating countries in a geographical sense to ensure that long-distance trans-boundary shipment of SF and HLW among participants could be minimized,

* **Financial Arrangement** among participating countries, including cost sharing and financial compensations, with the service provider(s) receiving compensation from other contractual parties,

* **Protection Objectives** of the participating countries based on a rational set of safety, radiological and environmental standards and criteria for the safe/secure storage/disposal of SF and HLW,

* **Research Collaboration** among the participating countries to assure the paramount important of the safe and environmentally sound management of SF and HLW.

3. Conclusion (Potential Benefits of IMRSS)

The IMRSS could complement a country's national SF/HLW management system in such manner that it could alleviate a country's burden of not being able to site additional SF/HLW storage facilities. Once the SF is transferred into the IMRSS, the country could continue its reactor operation without the concern of premature shutdown due to loss of full-core reserve in the SF storage pool.

The IMRSS could provide the safe and secure storage of SF/HLW meeting all requirements of the IAEA's Joint Convention on the Safety of Spent Fuel and Radioactive Waste Management. Fissile materials under the IMRSS will also be subject to IAEA's safeguards and security surveillance. As a result, the IMRSS could enhance transparency and lessen the proliferation concern.

The IMRSS could provide the forum for contact and dialogue between prospective contractual parties. For example, in East Asia, the IMRSS could ferment the interest between China and Taiwan, and may lead to China's willingness to store Taiwan's SF and radioactive wastes. The same possibility could also exist between Russia and Japan. Working under the IMRSS framework, the two countries could jointly develop storage sites in the Russian Far East/Siberia[3], or in one of the disputed northern islands, for the purpose of storing Japan's civilian and Russian's naval SF. Other countries (S. Korea) could also join in the formation of such IMRSS framework.

The IMRSS could potentially improve the overall SF/HLW management system through better allocation of resources (remote land mass and financial sharing), cognisant research collaboration, and adaptation of international safety standards and criteria. It also could improve the public perception on nuclear power program, by facilitating an internationally acceptable solution for SF/HLW management and disposal.

The IMRSS could serve as encouragement to emerging countries which contemplate the introduction of nuclear power, by demonstrating that one of the most intractable problem associated with nuclear power generation could be satisfactorily addressed.

Reference:

1 IAEA INFCIR/549, "Communication received from certain member states concerning their policies regarding the management of plutonium," 16 March 1998.

2 Measures to strengthen international co-operation in nuclear, radiation and waste safety, (a) Joint convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste management, IAEA, GOV/INF/821-GC(41)/INF/12, 22 September 1997.

3 M. Bunn, N. J. Numark, and T. Suzuki, "A Japanese-Russian Agreement to Establish a Nuclear Facility for MOX fabrication and spent fuel Storage in the Russian Far East," private communication, October 20, 1998.

Table 1 Global Spent Fuel Storage Capacity and Inventory (tHM) and the Need for Additional Storage in the Next Five Years

Region[1]	At-Reactor storage capacity	At-Reactor storage inventory	5-year storage capacity[2]	Additional discharge inventory[3]	storage needed[4]
	(a)	(b)	(c)	(d)	(e)
North America[5]	93,000	58,000	6,600	17,000	No
Western Europe[6]					
w/France & UK	24,500	12,500	25,000	14,200	No
w/o France and UK	11,000	6,000	8,000	3,700	No
Scandinavia[7]	2,200	900	3,000	1,400	No
South Asia[8]	1,700	440	460	1,200	No
Eastern Europe[9]					
w/Russia	11,000	6,000	9,400	5,500	No
w/o Russia	5,400	3,000	8,000	2,400	Soon
South America[10]	1,800	1,300	400	650	Soon
East Asia[11]	17,800	10,700	1,100	8,500	Yes
South Africa	670	390	---	185	No

Footnotes:

1 This is the total for a region, individual plant or unit in a country may have its specific need for storage capacity
2 This may include on-site wet or dry storage, off-site storage and storage at reprocessing facilities
3 This is total discharged spent fuel inventory for the next five years
4 (e) is calculated as (a+b+c+d). No if positive, and Yes if negative
5 Region includes Canada, Mexico, and USA
6 Region includes Belgium, France, Germany, Netherlands, Spain, Switzerland, and UK
7 Region includes Finland and Sweden
8 Region includes India and Pakistan
9 Region includes Armenia, Bulgaria, Czech Republic, Hungary, Romania, Russian Federation, Slovakia, and Slovenia
10 Region includes Argentina and Brazil
11 Region includes China, Japan, South Korea, and Taiwan

Table 2 Separated Plutonium Inventories as reported in the Plutonium Management Guidelines

Country (report date)	Unirradiated separated Pu in stores (kg)	Unirradiated separated Pu in fabrication (kg)	Plutonium in MOX @ reactor (kg)	Unirradiated separated Pu elsewhere (kg)	**Total (kg)**
Japan (3/12/97)	500	3,300	800	400	**5,000**
Russia (1/7/96)	27,200	-	63	870	**28,133**
Germany (5/12/97)	-	-	-	-	**-**
Belgium (12/12/97)	-	2,600	100	-	**2,700**
Switzerland (12/12/97)	-	-	600	100	**700**
US (3/12/96)	-	<50	4,600	40,400[1]	**45,050**
China (3/12/96)	-	-	-	-	**-**
UK (3/12/96)	52,100	500	2,200	-	**54,800**
France (3/12/96)	43,600	11,300	5,000	5,500	**65,400**
Total[2]	123,400	17,750	13,363	47,270	**201,783**
Total[3]	123,400	17,750	13,363	6,870	**161,383**

Footnotes:

1 The US may have reported this amount from the excess weapons-grade plutonium stock
2 Total includes the footnote 1 stock
3 Total does not include footnote 1 stock

About the Author

Jor-shan Choi, currently a staff member at the International Atomic Energy Agency (IAEA), was previously affiliated with Lawrence Livermore National Laboratory where he conducted this independent study for the Pacific Nuclear Council's Steering Committee on SF/HLW Management. He has a Ph.D. in Nuclear engineering from U.C. Berkeley, and his works include nuclear fuel cycle and waste management, criticality safety and radiation protection, nuclear system design and analysis, and regional compact approach for the peaceful use of nuclear energy, especially for East Asia.

Jor-Shan Choi's e-mail address: J.S.Choi@iaea.org

Shifting Spent Fuel Policy from Reprocessing Toward Interim Storage: Case Studies in Germany, Japan, and Korea

Mark Hibbs, European Editor of *Nuclear Fuel and Nucleonics Week*, McGraw-Hill, Inc.

Three leading nuclear power-generating countries, Germany, Japan, and South Korea, are now on the threshold of re-orienting their spent fuel management policies away from strategies centered on near-term reprocessing and plutonium recycle and toward a path where interim storage will play a major or central role. All three countries are now anticipating construction of dry storage facilities to absorb spent fuel arisings not covered by reprocessing commitments.

Germany, Japan, and South Korea together have an installed capacity of just under 80,000 MWe in nuclear power reactors, representing nearly 25% of the world's total installed capacity. Until now, all three countries have acquired a leading position in the expansion of nuclear power generation since the U.S. relinquished that role after the Three Mile Island-2 accident in 1979.

In parallel with construction of power reactors, since the 1970s Germany and Japan have prioritized the development of comprehensive national fuel cycle infrastructures; back-end strategy in both countries has therefore been based on wet storage of spent fuel at reactor sites, followed by reprocessing and recycle of plutonium and eventual reuse of reprocessed uranium (REPU). In South Korea, where very little fuel cycle infrastructure has been established, spent fuel has been stored in reactor pools; until now, however, utility management has anticipated that spent fuel would, as in Japan and Germany, be reprocessed offshore and the recovered plutonium recycled, beginning sometime soon after 2000.

As the end of the century nears, however, signs are on the horizon that the spent fuel policies of all three countries are about to change significantly. If that happens, other nuclear-generating countries--including China, Belgium, and Switzerland--which likewise have established a reprocessing-oriented spent fuel policy, may also follow suit. A global shift in this direction would have an immense and negative impact on the spent fuel reprocessing industry centered in the United Kingdom and France.

Germany

Since the 1970s, reprocessing has been the dominant back-end solution, mandated by industry and government in the interest of national resource and technological autarky. German utilities reprocessed some spent fuel at a pilot reprocessing facility (WAK) located at the Karlsruhe Nuclear Research Center, now decommissioned. Most German spent fuel has been reprocessed by Cogema in France, and some by British Nuclear Fuels plc (BNFL). Since the early 1990s, when Germany's installed nuclear capacity leveled off at 24,000 MWe, German power reactors have been producing about 500 metric tons of heavy metal in spent fuel per year (MTHM)/y. This material has been routinely stored in pools at reactor sites and then transported after several years of cooling to reprocessing plants in France and Britain.

Until 1994, the Federal Atomic Energy Act expressly required the reprocessing of German spent fuel and the recycling of recovered fissile materials. Then, however, in response to utility demands for more flexibility, in part vis-a-vis foreign reprocessors, German law was changed to allow utilities the option of geological disposal of their spent fuel. In practice, this has meant that nominal exploration of a geological repository at the Gorleben salt dome has continued to be financed by utilities (thus far about $2-billion has been spent on waste disposal research and development) while spent fuel has accumulated at reactor pools and has been slated for interim storage in two central storage facilities at Gorleben and Ahaus. Since 1995, however, mass demonstrations, featuring violent battles between masked protesters armed with crude weapons and riot police, have interrupted routine shipments of spent fuel to the storage sites. The additional physical protection mustered for three shipments to the storage facilities carried out since 1995, consisting of vitrified reprocessing waste returned from abroad and a handful of spent fuel casks sent from German reactors, has cost more than $60-million.

Finally, in mid-1998, Germany's nuclear regulatory authority banned all shipments of spent fuel and waste inside the country, after the government was embarrassed by revelations that, for over a decade, very small amounts of contamination on the surface of transports, had been routinely discovered but not reported to regulators. The transport ban is still in effect.

Since 1994, two utilities have announced that, for three German reactors, they will not carry out reprocessing under contracts with BNFL but will instead store their fuel in Germany for an indefinite period of time, followed by later geological disposal. One of these has now been awarded a nuclear license for construction of a facility to hold about 120 dry storage casks at the reactor site. It is expected that others will follow suit.

In September, 1998, a national election removed from office a national government which had been steadfastly in favor of nuclear energy since 1983. The new government of formally antinuclear Social Democrats (SPD) and environmentalist Greens in October agreed to a coalition pact which called for amending the German Atomic Energy Act to mandate a phase-out of Germany's 19 power reactors and an end to spent fuel reprocessing. The agreement specifically mentioned the government's desire to store spent fuel at reactor sites in lieu of Gorleben and Ahaus.

In parallel, the new government decided to hold negotiations with the power industry over the timetable and implementation of steps to wind down Germany's nuclear energy program. Legislative amendments and government-utility negotiations will begin in January, 1999.

While both sides are expected to clash bitterly over the issue of financial compensation to utilities for loss of capital investment, there is a basic agreement on both sides that reprocessing of German spent fuel will be terminated in favor of geological disposal of spent fuel which in practice will mean long-term interim storage. While utility CEOs have broadcast hardline positions against the government's nuclear phase-out plans, in fact their commitment to reprocessing is weak.

German utilities have accumulated over 10 MT in separated plutonium which is now being stored abroad. About half of German reactors have licenses to load mixed-oxide (MOX), but current MOX strategy would not suffice to build down Germany's "plutonium mountain" to zero so long as spent fuel continues to be reprocessed.

Utilities' commitment to the plutonium fuel cycle is strongest at the CEO-level of powerful energy multinational companies such as VEBA, VIAG, and RWE, where reprocessing in France and Britain is seen as emblematic of Germany's overall commitment to nuclear power and to a "Europeanization" of industry.

But the symbolic function of reprocessing and the "closed" fuel cycle is of no interest to reactor spent fuel management. It has made clear that, since deregulation of Europe's power markets is expected to make strides during the next decade, and since the natural gas and world coal markets continue to provide cheap fossil fuels, even the relatively marginal cost factors involved in reprocessing and MOX fuel fabrication and fuel management (compared to the total cost of nuclear electricity generation) may be significant enough to determine whether a utility can justify continued operation of its reactors.

In 1998, important German utilities decided to set up profit center subsidiaries which will directly pit nuclear reactors against fossil-fueled plants. Facing this challenge, reactor management is aggravated that Cogema has charged German utilities charged prices for reprocessing which are nearly twice what Cogema is charging French reactors. The cost of MOX fuel production is also prohibitively high. Some reactors which have MOX licenses have chosen not to load all of the MOX fuel they are allowed, since they are under pressure from utility management to cut generation costs. Finally, in-core strategies are now aiming to increase discharge burnup levels from about 32,000 megawatt-days/MT, which obtained when Germany began reprocessing, to 50,000 MWd/MT or more. At these levels, 70% of the electrical energy generated is directly due to the burning of plutonium. Also, at the higher burnups, the enrichment and conversion requirements for using REPU fuels involve heavy commercial penalties.

For these reasons, it can be anticipated that, when government-industry negotiations begin in January, 1999, while there will be acrimonious negotiation over the issue of compensation of Cogema and BNFL, there will nonetheless be a basic agreement by German industry and government that reprocessing will be terminated.

Until this May, about 75 transports of German spent fuel were carried out to Britain and France each year. Should no more German spent fuel be sent abroad for reprocessing, reactors may be forced to shut down unless more space is made available for storing spent fuel, since pools are becoming full. One reactor's spent fuel pool is already too full to allow unloading of a whole core (a space cushion required under German safety rules) after the next refueling outage, scheduled in early 1999. Without additional storage capacity (absent shipment of spent fuel to reprocessors or storage elsewhere in Germany) the reactor will have to be indefinitely shut. Two more reactors will reach the same critical situation at the end of 1999 or early 2000.

In pending talks, it is expected that government and industry will agree on procedures and demonstrate political will to license and construct dry storage facilities at reactor sites in time to be operated beginning in three years. It is anticipated that the storage infrastructure will

be licensed for a period of at least 40 to 50 years. Industry also wants the government to restore nuclear transports inside Germany to allow reactors to shunt spent fuel out of pools which are nearly full, averting the specter that reactors may be forced shut before dry storage facilities at the sites are in place.

Japan

Unlike in Germany, Japan's spent fuel management reality is changing incrementally without the impetus of any dramatic political changes. In Japan, the sheer numbers suggest that government and industry must adjust fuel cycle policy, but the scope of the problem has not yet been openly acknowledged by Japanese leadership.

Thus, Japan's current spent fuel strategy is officially the same as it has been since the beginning of Japan's nuclear energy program: wet storage of spent fuel at reactor sites, followed by domestic reprocessing (at a pilot plant) and foreign reprocessing of spent fuel and, then, increased domestic reprocessing soon after 2000 when an 800 MTHM/y reprocessing plant at Rokkasho-mura is completed and operating. Recovered plutonium and REPU from Cogema and BNFL are to be repatriated and recycled, while a MOX plant is to be built in Japan to use plutonium feedstock recovered by reprocessing at Rokkasho-mura.

But the plan to reprocess Japanese spent fuel is in difficulty and the timetable has been delayed, and may be subject to considerable further delays depending on pending decisions by Japanese leaders. Meanwhile, spent fuel is piling up at Japan's 50 power reactors. In 1985, 1,500 MTHM in spent fuel were being stored at the reactors. This increased to 2,800 MTHM in 1990 and to 5,100 MTHM in 1995. The expansion of Japan's reactor population in the last two decades has increased annual spent fuel discharges from about 500 MTHM/y to over 1,000 MTHM/y and, it is expected, to about 1,300 MTHM/y shortly after 2000. Because of bureaucratic difficulties, efforts by Japanese utilities to move toward higher burnups, and less spent fuel discharges, have been stalled until recently.

By the end of 1997, Japanese power reactors had discharged a total of 125,000 MTHM in spent fuel. Of this, 940 MT was reprocessed at a domestic reprocessing plant at Tokai-mura; about 5,600 MTHM was sent to Cogema and BNFL. The rest, about 6,400 MTHM, is now in storage in pools at reactor sites.

The reprocessing plant under construction at Rokkasho-mura was planned as the first of two identical facilities. Construction of the second of these has now been indefinitely postponed, leaving as much as 500 MTHM/y of spent fuel arisings uncovered by reprocessing commitments. At the same time, Japanese plans call for adding twenty new reactors during the next 15 years. It is not ancipated that all these units will be built, but those which will be built will discharge still more spent fuel not covered by reprocessing commitments. According to official Japanese plans, expected discharges will be 1,400 MT/y in 2010 and 1,900 MT/y by 2030.

Japan's Science and Technology Agency (STA) and the Ministry of Interntional Trade and Industry (MITI) have now reacted to these development by embarking on a plan to add spent fuel storage capacity. According to MITI, Japan will need an additional storage capacity of for least 1,000 MT in spent fuel by 2020, and 6,000 MT in 2030, above that already foreseen by

Japan's "nuclear vision" plans, which were drafted on the expectation that spent fuel reprocessing will continue to expand in Japan.

Several strategies are now in place to address the steady advance of Japan's unreprocessed spent fuel inventory in the coming years. Utilities are now working with MITI on a program of increasing discharge burnups from a current level of about 35,000 MWd/MY to 45,000 MWd/MT. Implementing this will have the same economic impact on utility management planning as is now the case in Germany, particularly since MITI has already put utilities on notice to reduce nuclear generating costs, already among the highest in the advanced industrialized world.

At the same time, utilities are sounding out prospects of signing additional reprocessing contracts with Cogema and BNFL. Industry officials in Japan report that Japanese utilities would be interested in new contracts only on the basis that they are "flexible" and that utilities may elect to send their spent fuel to Britain and France for a considerable period of interim storage prior to any decision to reprocess the spent fuel and then repatriate plutonium as MOX. Utility officials studying the matter say they seek agreements with foreign reprocessors which would allow Japanese fuel to be stored offshore "for up to several decades" prior to reprocessing.

Also, Japan now expects to construct more spent fuel storage capacity. MITI and STA this year formally proposed construction of at least two central storage facilities, either pools or dry storage compounds. The Japanese legislature is now expected to approve plans before May, 1999 to erect additional capacity needed to be ready by 2010. According to some Japanese press reports, these facilities may be large enough to store 6,000 MTHM in spent fuel by 2010 and 15,000 MTHM ten years later.

Japanese industry and government are now considering how to proceed in its own reprocessing program. While the second 800 MTHM/y facility at Rokkasho-mura is not expected to be built, the fate of the first incomplete one is under discussion. Japanese industry officials report that, except for head-end storage pools, which are designed to have a capacity of 3,000 MT and which are completed, the rest of the plant is only about 10% finished despite a formal completion target of 2003. Also, the cost of construction has seriously escalated. According to current industry projections, the first 800 MTHM/y plant will cost just under $20-billion. With utilities under pressure from MITI to cut costs, utility management has considered delaying operation of the Rokkasho-mura plant for at least several years after it is completed, but no decision has been taken as yet. Willingness to alter the timetable for construction and operation is complicated by the requirement of local authorities that spent fuel may be stored in pools at the site only under condition that they are reprocessed. As of the end of 1998, 1,000 MT in spent fuel should have been transferred from reactor sites to the pool at Rokkasho-mura; in fact, because of local opposition, only 8 MT has been brought to the site.

Additional interim storage might also be needed if plans to burn MOX fuel are not expeditiously realized, since Japan is under international pressure to keep its plutonium supply and demand situation in balance. Japan faces a serious potential plutonium overhang as a result of the accident which three years ago which indefinitely shut the Monju breeder reactor. At the time, Japanese industry predicted the reactor would restart in two years or less; the reactor is still shut. The accident has also had a negative impact on efforts by Japan to license reactors to burn

MOX. Utilities are still awaiting approval by prefectural governments in Fukushima, Fukui, and Niigata to load about 35 MT of plutonium in MOX during the period 1999-2010 in 18 reactors.

Japanese utility management is now concentrating its effort to get political approval of sites for interim storage of more spent fuel on Japanese territory. In parallel, management has begun to entertain the theoretical option of sending some Japanese spent fuel to an offshore retrievable interim storage facility on the basis of a firm agreement that the spent fuel would be stored there for a specific limited period of time.

South Korea

At the same time when the new German federal government pronounced that it would mandate a retreat from spent fuel reprocessing in France and Britain, leaders in South Korea independently announced that South Korea would not reprocess any of its spent fuel abroad but would continue to store it for an indefinite period of time.

In 1997, top management at Korea Electric Power Corp. (Kepco) had sought arrange informal approval by the U.S. government to allow U.S.-origin spent fuel to be reprocessed offshore in Britain or France and the plutonium burned in Korean reactors as MOX. Korean experts had discussed setting up an experimental MOX program for Korean reactors with fuel cycle firms in Britain and France.

But in early 1998, after a new South Korean government was elected, a former economics professor who had lived in the U.S. since 1968, Young-Shik Chang, was appointed CEO at Kepco. Chang promptly informed nuclear planners in the Ministry of Science and Technology (MOST) and spent fuel management officials at Kepco that the utility's spent fuel inventory would not be reprocessed.

This decision, combined with hints by Chang that he may seek to increase future fossil fuel consumption at the expense of nuclear power expansion, as well as the utility's decision this fall to scrap a list of nine potential sites for future nuclear power plant construction, has led to some internal speculation in Korean industry and government that the new leadership does not strongly support Korea's nuclear power development program.

Independently of this, the no-reprocessing decision has immediately added pressure on reactor management to assure that there will be sufficient storage space for spent fuel at Kepco's four existing reactor sites for the period after 2006, when capacity may be exhausted. At Kori site, which hosts four PWRs, spent fuel from the oldest unit, Kori-1, has been moved to the pools at Kori-3 and -4 because its pool is full. Kepco had been adding high-density racks into the Kori-4 pool. Finally, Kepco is seeking to construct a dry storage facility for Kori spent fuel; setting up dry storage, which had been delayed for several years, is now expected to be intensified. Korean industry officials reported this fall that, thus far, Kepco is looking at the possibility of setting up U.S.-type horizontal storage infrastructure as well as vertical concrete cannister storage infrastructure. Thus far, Kepco has not seriously pursued the possibility of storage in metal casks. The Kori site holds slightly less than 1,000 MTHM in spent fuel; its total capacity is 1,536 MTHM.

The situation is less critical at two other PWR sites, Yonggwang and Ulchin. Yonggwang has a capacity to hold 1,271 MTHM and Ulchin 708 MTHM. Both pools are less than half full at present. At Yonggwang, Kepco has set up a contingency plan to re-rack pools, providing additional storage until 2010. For Ulchin, the contingency plan calls on construction of dry storage capacity at the site.

Spent fuel output is poised to increase at the Wolsong PHWR site from 100 MTHM/y to about 400 MTHM/y when Wolsong-1 is joined by three more Candu-6 reactors by 2000. Wolsong spent fuel is already being dry stored; the low-burnup spent fuel is put in silos, each of which can hold nine stainless steel baskets which in turn can store 60 Candu spent fuel bundles. In 1992, the Wolsong site had a capacity of 60 silos. This was then augmented by additional construction of 80 more silos. Kepco plans to continue expanding the capacity for storage of spent PHWR fuel on the Wolsong site. It is expected that all or most of this spent fuel will be in dry storage for 50 years or more while Korea looks for a geological repository site, either in Korea or abroad.

Utility management reported this fall that Kepco's current planning provides enough storage space for all its spent fuel until 2006. Contingeny plans will provide a cushion of at least four more years. It may be possible to use existing capacity for some years beyond 2010 if space is optimized by shunting PWR spent fuel between reactor sites, but thus far this is not formally planned.

China

China is another country which, more recently than others discussed above, has launched an ambitious nuclear power program in tandem with a program to develop a reprocessing infrastructure. China expects to discharge about 60 MTHM from three reactors until 2002. Assuming that China's five-year plan for 1996-2000 is implemented, and eight more power reactors are built by the early 2000s, spent PWR fuel arisings will be 168 MTHM/y in 2005.

In parallel, China is building a pilot reprocessing plant to handle about 50 MTHM/y; this is expected to be completed sometime just after 2000. Chinese planners are counting on spent fuel from the two 1,000-MWe Daya Bay PWRs to be delivered to the head end of the plant in 2000, because the spent fuel pools at Daya Bay will be full by then.

However, as is the case at Rokkasho-mura in Japan, the construction of a head-end with a storage pool is the most advanced part of the Chinese reprocessing plant project. The pool is a modular design and a single pool can hold about 550 MTHM in spent fuel.

Daya Bay sells electricity to Hong Kong, and shareholders in the project there are weighing their spent fuel management options. Industry officials reported that, while China wants Daya Bay spent fuel to be reprocessed, investors may prefer to indefinitely store spent fuel unless the costs and logistics of reprocessing and plutonium recycle in China justify a "closed" fuel cycle. In particular, the infrastructure for moving spent fuel from China's east coast reactor sites to the reprocessing plant in northwest China is not yet well-developed. If shareholders are not satisfied the case for near-term reprocessing is a strong one, they may opt instead for construction of additional pools or dry storage capacity for spent fuel. Professor Atsuyuki Suzuki of the University of Tokyo stated recently before the Center for Security and International

Studies in Washington, D.C. that "my impression is that China will probably be faced not in the far distant future with a difficulty which is similar to Japan's current situation."

Summary

Because the economics and political acceptance of reprocessing and plutonium recycling programs have come under intense pressure, key countries which have thus far favored a reprocessing strategy have abandoned it or appear to be ready to moderate their policy through the introduction of greater long-term interim storage of more spent fuel. For political reasons, Germany appears to be closest to taking the consequences of disenchantment in industry with the near-term prospect of intensified plutonium recycle. South Korea appears to have embarked on a similar political course as Germany but, because no spent fuel has been reprocessed so far, pressure to arrange for dry storage capacity is less immediate than in Germany. In Japan, momentum is building toward what Suzuki calls a "re-optimization" of spent fuel management policy away from full-blown plutonium recycle and toward a mixed strategy of reprocessing and interim storage of spent fuel.

About the Author

Mark Hibbs is European Editor of Nuclear Fuel and Nucleonics Week, published in Washington, D.C. by McGraw-Hill, Inc. Based in Europe since 1986, Mr Hibbs left the Financial Times organization and concentrated on nuclear energy issues since the Chernobyl accident. His investigations into proliferating nuclear programs and activities have been cited for professional honors, including work on Iraq's clandestine nuclear program (1991), South Africa's uranium enrichment and weaponization program (1993), and illicit trafficking of Soviet-origin nuclear materials (1995). Mr Hibbs has devoted more recent attention to nuclear energy programs in China, the Koreas, Japan, and Taiwan.

Mark Hibbs' e-mail address: mhibb@mh.com